COMPARISON OF PILOT PERFORMANCE USING A CONVENTIONAL AND A FREQUENCY SEPARATED DISPLAY ADI

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Abstract

This report presents the results of an experimental program designed to study the relative merits of a conventional moving horizon attitude director indicator (ADI), and an alternate ADI called a frequency separated display. The program is based on the investigation of the performance of naïve test subjects (with no previous ADI experience) while flying a number of lateral control tasks under instrument meteorological conditions in a flight simulator set up as a T-33 jet trainer.

Four lateral flying tasks were developed and employed: level tracking, heading changes, sudden attitude upsets, and unusual attitude recoveries. In addition, two secondary tasks (one audio and one visual) were employed in order to increase the overall workload and to provide a measure of level of attention required by the primary flying task.

A total of 24 subjects participated in the study, with approximately 14.5 hours of simulator time each. Both objective and subjective measurements were taken, with the independent experimental variables being: ADI type, simulator motion present/absent, and secondary task type.

The experimental results indicate that ADI type was not significant in the heading changes task. However, subjects displayed improvement in performance using the frequency-separated display for the level tracking tasks.

The primary measurement of pilot performance in the sudden attitude upsets and unusual attitude recoveries was the number of control reversals (where the pilot aileron input is in the opposite direction to that which is required to return the aircraft to wings level). Fewer control reversals (as defined using two different criteria) were committed using the frequency-separated display for sudden attitude upsets. The same improvement in performance was also noted when using the frequency-separated display for unusual attitude recoveries for the more stringent of the two criteria. For both sudden attitude upsets and unusual attitude recoveries, the pilot aileron input also appeared to be more consistent with less overshoot when using the frequency-separated display.

Overall, performance with the frequency-separated display was generally either similar to or superior to that with the conventional ADI.

Résumé

Le présent rapport présente les résultats d’un programme expérimental conçu pour étudier les mérites relatifs de l’indicateur directeur d'assiette (ADI) à horizon mobile classique et d’un ADI alternatif appelé ADI à affichage à espacement de fréquence. Le programme repose sur l’analyse des performances d’un groupe de sujets d’essai novices (n’ayant aucune expérience de l’ADI) qui ont exécuté un certain nombre de tâches de pilotage reliées au contrôle en roulis dans des conditions météorologiques de vol aux instruments à bord d’un simulateur de vol configuré pour simuler un avion d'entraînement à réaction T-33.

On a préparé et utilisé quatre tâches de pilotage reliées au contrôle en roulis : maintien du vol en palier, changements de cap, changements brusques d’assiette et rétablissements d’assiettes anormales. De plus, on a utilisé deux tâches secondaires (une audio et l’autre visuelle) dans le but d’augmenter la charge de travail globale et de fournir une mesure du niveau d’attention requis pour exécuter la tâche de pilotage primaire.

Un total de 24 sujets ont participé à l’étude, et ils ont passé environ 14,5 heures chacun dans le simulateur. Des mesures objectives et subjectives ont été prises, et les variables expérimentales indépendantes étaient : le type d’ADI, la présence ou l’absence de mouvement dans le simulateur et le type de tâche secondaire.

Les résultats expérimentaux indiquent que le type d’ADI n’avait pas d’influence significative dans le cas des changements de cap. Toutefois, les sujets ont démontré des performances supérieures dans l’exécution des tâches de maintien du vol en palier avec l’affichage à espacement de fréquence.

La principale mesure des performances du pilote dans le cas des changements brusques d’assiette et des rétablissements d’assiettes anormales a été le nombre d’inversions des commandes (où le pilote braque les ailerons dans le sens inverse à celui qu’il faut pour ramener les ailes à l'horizontale). Il y a eu un plus petit nombre d’inversions des commandes (selon deux critères différents) avec l’affichage à espacement de fréquence dans le cas des changements brusques d’assiette. On a constaté une amélioration des performances similaire lorsqu’on utilisait l’affichage à espacement de fréquence pour les rétablissements d’assiettes anormales dans le cas du plus rigoureux

des deux critères. En ce qui concerne les changements brusques d'assiette et les rétablissements d'assiettes anormales, le braquage correct des ailerons par le pilote a également semblé plus constant et a présenté moins de dépassements avec l'affichage à espacement de fréquence.

Globalement, les performances avec l'affichage à espacement de fréquence ont été généralement semblables ou supérieures qu'avec l'ADI classique

EXECUTUVE SUMMARY

Background

The Canadian Forces are upgrading and improving the avionics of the existing fleet of aircraft. This provides an opportunity to evaluate alternative methods of displaying information to those currently used. The purpose of this work is to compare two different methods of displaying aircraft pitch and roll information, although only the roll component was examined here. The incentive for this work is improved flight safety, particularly under unexpected or sudden changes in aircraft orientation.

The current method of displaying aircraft pitch and roll on the Attitude Director Indicator (ADI) may not be the best and may result in misinterpretation leading to control reversal and loss of aircraft control. Studies of alternative ADI formats suggested that other approaches might provide more easily interpreted displays, particularly in situations where the pilots "seat-of-the-pants" perceptions do not match the aircraft instrumentation displays. While the literature is suggestive, the studies generally used small numbers of subjects and fixed-base simulators. This leads to questions about the reliability of the conclusions and their extension to in-flight operations, so the current work was developed to use more subjects and assess the differences between moving and motion-base simulator assessments.

Approach

The UTIAS Flight Research Simulator has been configured to represent a fixed-wing aircraft (T-33) with the capability of representing the full range of ADI configurations described above. An altitude-hold autopilot has been included to simplify the flight task when novice test subjects are employed. Disturbance signals have been developed to represent the effects of turbulence and trailing vortices on the response of the aircraft.

An experimental program was designed to study the relative merits of a conventional moving horizon ADI and a frequency-separated display ADI. The program is based on the investigation of the performance of 24 naïve test subjects while flying a number of lateral control tasks under instrument meteorological conditions.

Four lateral flying tasks were developed and employed: level tracking, heading changes, sudden attitude upsets, and unusual attitude recoveries. In addition, two secondary tasks (one audio and one visual) were used to increase the overall workload and measure differences in the level of attention required by the primary flying task.

Results

During routine flying, subjects were able to maintain level flight slightly better with the frequency-separated display, but the performance differences between ADIs were small and no differences were found during heading changes.

Generally, fewer control reversals were committed during sudden attitude upsets using the frequency-separated display than the conventional ADI (48 vs 69 reversals during 224 trials) although unusual attitude recovery showed little difference (35 vs 32 reversals in 448 trials). Aileron input appeared to be more consistent with less overshoot when using the frequency-separated display during both sudden attitude upsets and unusual attitude recoveries.

Subjects were more prone to making control reversals when motion was added to the simulation during sudden upset (71 with motion vs 46 without motion, 224 trials), however the opposite was true for unusual attitude recovery (30 with motion vs 37 without motion, 448 trials).

In the majority of conditions, performance with the frequency-separated display was at least similar to and often superior to that with the conventional ADI. Although performance with the frequency-separated display was similar to the conventional ADI during unusual attitude recoveries, performance with it was better when recovering from sudden upsets.

Implications

The investigation suggests that a frequency-separated display ADI may only provide a small benefit over the conventional, moving-horizon ADI during routine flying, however, this new format may lead to safer performance when recovering from upset. Whether similar results can be obtained with experienced pilots remains to be determined but the results obtained here suggest further study is warranted.

SOMMAIRE

Contexte

Les Forces canadiennes procèdent présentement à la mise à niveau et à l'amélioration de l'avionique des aéronefs de sa flotte. Cette démarche fournit l'occasion d'évaluer d'autres méthodes d'affichage des renseignements que celles présentement en usage. Le présent travail a pour but de comparer deux méthodes différentes d'affichage des données de tangage et de roulis des aéronefs, quoique la présente étude ne porte que sur le roulis. Ce travail est motivé par la recherche d'une plus grande sécurité des vols, surtout dans les cas où l'aéronef subit des changements d'orientation brusques ou imprévus.

La méthode actuelle d'affichage des données de tangage et de roulis des aéronefs sur l'indicateur directeur d'assiette (ADI) n'est peut-être pas la meilleure, car elle peut conduire à des erreurs d'interprétation menant à des inversions des commandes et à des pertes de maîtrise. Les études portant sur des formats alternatifs d'ADI ont laissé croire que d'autres types d'approche pourraient fournir des affichages plus faciles à interpréter, surtout dans les situations où les sensations physiques des pilotes ne correspondent pas aux affichages des instruments de l'aéronef. Même si la documentation laisse entendre beaucoup de choses, les études sont généralement basées sur un nombre limité de sujets qui utilisent des simulateurs sans système de mouvement. On peut donc s'interroger sur la fiabilité des conclusions et sur la possibilité de les étendre aux opérations en vol. C'est pourquoi on a élaboré le présent travail afin d'utiliser un plus grand nombre de sujets et d'évaluer les différences entre les simulateurs avec et sans système de mouvement.

Approche

On a configuré le simulateur de recherche sur le vol de l'UTIAS pour qu'il simule un avion à voilure fixe (T-33) ayant la capacité de représenter toute la plage des configurations ADI susmentionnées. On a inclus une capacité de maintien automatique de l'altitude afin de simplifier la tâche de pilotage lorsque les sujets des essais étaient des novices. On a élaboré des signaux de perturbation afin de représenter les effets des turbulences et des tourbillons de sillage sur le comportement de l'avion.

On a conçu un programme expérimental afin d'étudier les mérites relatifs d'un ADI à horizon mobile classique et d'un ADI à affichage à espacement de fréquence. Le programme est basé sur l'analyse des performances de 24 sujets d'essai novices qui devaient accomplir un certain nombre de tâches de pilotage reliées au contrôle en roulis dans des conditions météorologiques de vol aux instruments.

On a préparé et utilisé quatre tâches de pilotage reliées au contrôle en roulis : maintien du vol en palier, changements de cap, changements brusques d'assiette et rétablissements d'assiettes anormales. De plus, on a utilisé deux tâches secondaires (une audio et l'autre visuelle) dans le but d'augmenter la charge de travail globale et de mesurer le niveau d'attention requis pour exécuter la tâche de pilotage primaire.

Résultats

Au cours des vols ordinaires, les sujets sont parvenus à maintenir légèrement mieux le vol en palier avec l'affichage à espacement de fréquence, mais les différences de performances entre les deux types d'ADI étaient mineures et aucune différence n'a été notée lors des changements de cap.

De façon générale, les pilotes ont commis moins d'inversions des commandes au cours des changements brusques d'assiette lorsqu'ils ont utilisé l'affichage à espacement de fréquence plutôt que l'ADI classique (48 contre 69 inversions en 224 essais), bien que dans le cas des rétablissements d'assiettes anormales la différence était minime (35 contre 32 inversions en 448 essais). Le braquage correct des ailerons a semblé plus constant et a présenté moins de dépassements avec l'affichage à espacement de fréquence dans le cas des changements brusques d'assiette ainsi que des rétablissements d'assiettes anormales.

Les sujets ont été davantage portés à commettre des inversions des commandes lorsqu'on a ajouté le mouvement à la simulation au cours des changements brusques d'assiette (71 avec mouvement contre 46 sans mouvement en 224 essais), mais l'inverse s'est produit pour les rétablissements d'assiettes anormales (30 avec mouvement contre 37 sans mouvement en 448 essais).

Dans la plupart des conditions, les performances avec l'affichage à espacement de fréquence étaient au moins équivalentes et souvent supérieures à celles avec l'ADI classique. Même si les performances avec l'affichage à espacement de fréquence étaient semblables à celles avec l'ADI classique au cours des rétablissements d'assiettes anormales, elles étaient néanmoins supérieures lors des rétablissements après les changements brusques d'assiette.

Conclusions

L'enquête laisse croire que l'ADI à affichage à espacement de fréquence ne présente sans doute qu'une légère amélioration par rapport à l'ADI à horizon mobile classique au cours des manoeuvres de routine, mais que ce nouveau format peut conduire à des performances plus sûres lors des rétablissements après des changements brusques d'assiette. Il reste encore à déterminer si les résultats seraient comparables avec des pilotes expérimentés, mais les résultats déjà obtenus semblent justifier la poursuite des recherches.

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1 Background

On September 24, 1929, James Doolittle took off in an airplane with the cockpit completely covered, conducted a 20 mile flight, and returned to land at almost the same spot. This was the first recorded non-visual flight, and proved that flying an airplane using instruments alone was possible [1].

The primary instrument that allowed Doolittle to successfully conduct his flight was an attitude display, now called the Attitude Director Indicator (ADI). Although there are variations in the design of ADIs, all show the aircraft's orientation relative to the ground by the use of two symbols: an aircraft symbol, and an artificial horizon.

While many additional navigation instruments and displays have been developed, the ADI remains an important instrument in modern cockpits. In most cases, the ADI acts as the primary flight display under instrument flight. The ADI itself has changed with the introduction of "glass cockpits" that allow the display to be presented using colour graphics and computer generated symbology, but the information conveyed and the format in general use remains essentially unchanged.

1.1 Motivation for Research

On New Year's Day of 1978, an Air India Boeing 747 took off from Santa Cruz Airport, Bombay, bound for Dubai, UAE. On climb-out, Captain Kukar rolled 14-degrees right, and maintained this bank from 62 to 70 seconds after takeoff. He then allowed the plane to gradually return to wings-level. However, the plane continued to slowly roll into a 9-degree left bank.

The flight recorder showed that at this point, the captain made an abrupt left-aileron input, then momentarily reversed his input before going back to hard-over left. The captain maintained full left aileron as the jet went into a 108-degree left bank, 35 degrees nose down, and fell from 1460 feet to crash into the sea at 330 knots 101 seconds after takeoff, killing all 210 aboard [2].

The wreckage and flight recorders showed no evidence of any mechanical or electrical failures, fire, or explosion. However, the voice recorder indicated that the captain had been confused by one of his instruments, and the plane crashed while the flight engineer apparently attempted to diagnose the problem and direct the captain's attention to an alternate display.

A similar incident happened on September 8, 1994 to a USAir Boeing 737. Less than ten minutes before landing at Pittsburgh, the 737 encountered the wake vortex from another airplane up ahead, resulting in an abrupt attitude upset and a sudden loss of altitude. In an attempt to correct the flight attitude, the pilots inadvertently entered a spiral dive. Flight recorders show that the pilots held full aileron deflection in the direction of the rotation until the aircraft crashed into the ground at 301 miles per hour [3].

Such "graveyard spiral" accidents are common in general aviation, but are rare in military aviation, and almost never occur in commercial flight. Such accidents are almost always fatal, claiming about a hundred lives each year in the United States alone. On the rare occasions when they occur in commercial flight, such as the two incidents mentioned above, the results are catastrophic.

Almost all "graveyard spiral" accidents occur when the airplane is momentarily upset while conducting non-visual flight, resulting in the need for the pilot to recover from an unexpected attitude using instruments alone. It would appear that under certain circumstances, the ADI creates confusion, causing incorrect control movement to be initiated (a control reversal). Once a spiral develops, the pilot is further disoriented, diminishing the chances of recovery.

The confusion with the conventional ADI referred to above occurs when the pilot observes the displayed horizon symbol and mistakenly interprets it as his own aircraft symbol. This can occur both when the display is static and when it is moving. This in turn, can result in the pilot generating a control reversal leading to an upset. In addition, further confusion may be created under instrument flight conditions if the aircraft is allowed to slowly roll at a rate that goes undetected by the pilot's vestibular system. In this instance, when the pilot next monitors the ADI, he will see an indicated bank angle that conflicts with his perception of no bank angle. The process is further confused for the pilot if the aircraft is being buffeted by strong turbulence to the extent that significant random motions are being generated in all degrees-of-freedom.

2 Attitude Director Indicator (ADI) Displays

2.1 Human Factors and ADI Display Type

In a conventional ADI, such as the one used during Doolittle's flight, the airplane symbol remains fixed while the artificial horizon moves (Figure 2.1.1). The argument for using this type of display (called a "moving horizon" or "inside-out" display) is that there is consistency between the instrument display and the out-the-window view for pictorial-realism. To explain a possible cause of pilot confusion when using a moving horizon ADI, some understanding of human psychology is required.

The problem with moving horizon attitude displays has to do with the psychological phenomenon of figure and background. A pilot psychologically perceives an object as moving in relation to other objects in a visual field. The part that appears stationary is the background, while the moving object is the figure. When the entire visual field is moving relative to the observer's eyes, such as with head movement, the observer perceives that he is moving while the background is stationary. Thus, the problem is whether the attitude indicator maintains the figure and background relationship as the pilot shifts attention from the outside world to the instrument panel.

To the pilot, the actual horizon is normally accepted as the fixed or stable frame of reference. However, when the horizon is no longer visible, the pilot tends to shift to the cockpit of the aircraft as the stable reference. Thus all moving pointers, including the artificial horizon line, tend to be perceived as figures, not the background. The small moving line framed within the cockpit background cannot substitute for the actual horizon as a stable frame of reference. Thus, reacting to the horizon line as figure instead of background results in a reversed interpretation [4].

In response to the above, one may suggest the use of a "moving airplane" or "outside-in" display (Figure 2.1.1). In such a display, the artificial horizon remains fixed, while the aircraft symbol moves. Research seems to indicate strongly that a moving airplane display will result in a dramatic reduction of the probability of reversed interpretation [1]. However, the problem remains that the fixed artificial horizon will not be an accurate analog of the real world. Thus, pictorial-realism is compromised.

2.2 Alternative ADI Configurations

The alternative ADI configurations considered here are hybrids based on the moving airplane and the moving horizon ADIs, and are designed to be a compromise between the two for the best possible presentation in all flight conditions.

Findings suggest that when high frequency information is displayed (such as a sudden rolling manoeuvre), the moving display element should respond in the expected direction, but when low frequency information is displayed (such as in a turn), the element's direction of movement is not as crucial. Therefore, movement of the aircraft symbol should be determined by the frequency content of the input. For example, if the pilot initiates a turn to the left by movement of the control stick, the aircraft symbol should rotate to the left to coincide with his angular motion sensation. As the aircraft establishes the turn and angular motion subsides, the display should return to that of an inside-out ADI, thus providing an accurate analog of the outside horizon.

Two alternative ADI configurations have been proposed. The first type acts in the same manner as a conventional moving horizon display, except that the airplane symbol is rotated in proportion to aileron deflection (Figure 2.1.1). This display (which will be referred to as the Frequency Separated Display) gives the pilot an immediate impression of which direction the airplane will be rotating based on his input.

The second is called a Kinalog Display (which stands for Kinesthetic Analog, Figure 2.1.1). In such a display, the high-frequency component of aircraft roll is displayed in moving aircraft fashion. The true bank angle between the aircraft symbol and the horizon is displayed at all times, and the transition from moving airplane/horizon to moving horizon is made smoothly as the high frequency content disappears [5].

2.3 Past ADI Research

Studies into pilot responses to different ADIs have been conducted in the past, the most comprehensive of which were carried out at the University of Illinois during the 1970's. These systematic experiments, under the supervision of Johnson, Williges, and Roscoe, employed a simulator as well as flight experiments [5].

2.3.1 ADI Display Configurations

The various ADI configurations in both the simulator and the flight experiments were presented using a cathode ray tube (CRT) display. A total of eight ADI configurations were tested: moving horizon, moving airplane, frequency separated, and kinalog, each of which was presented in compensatory and pursuit mode [5]. The difference between pursuit and compensatory mode was the stimulus for error correction, and therefore their consequences will not be discussed in detail in this report. The eight ADIs tested are shown in Figure 2.3.1, and the way they function is described in the previous chapter, the only difference being the addition of a steering guidance dot for the pursuit mode.

2.3.2 Simulator Experiments

Preliminary experiments made use of a Link GAT-2 general aviation simulator to study response to various flight attitude and steering guidance displays while conducting navigation and tracking tasks. The GAT-2 has cockpit controls, flight dynamics, and instruments to simulate a light twin-engine aircraft. It has three degrees-of-freedom of motion, with the limits shown in Table 2.3.1.

2.3.2.1 Flight Tasks

Roscoe's simulator experiments consisted of two separate flight tasks, a Practice Task, and an Evaluation Task [5]. These flight tasks were designed to have the pilot navigate the aircraft to simulate common flight situations.

The Practice Task was designed to present a situation similar to radar-directed, air-to-air attack. During each trial, 24 simulated attacks were arranged in 3 groups of 8 heading commands followed by 48 seconds rest.

The heading change commands were 30, 45, or 60 degrees either to the left or the right, and were quasi-randomly chosen with the restriction that the terminal heading after each group of 8 commands was 360 degrees. The changes in commanded heading occurred every 24 seconds to allow sufficient time to null initial heading errors. The entire flight was conducted with continuous Gaussian noise inserted to represent vertical turbulence.

The Evaluation Task attempted to create a situation more frequently encountered by general aviation pilots. For this task, the pilot was required to follow a particular course while holding a specified altitude. Gaussian noise with a cut-off frequency of 0.05 Hz was inserted in both the vertical and horizontal directions to simulate the effects of turbulent air. The pilot was required to exercise control continuously in both pitch and roll in order to null the effects of the simulated turbulence.

2.3.2.2 Experimentation Subjects and Testing Sequence

The experimental subjects were 8 male pilots, all of whom were college students who had received their flight training at the Institute of Aviation of the University of Illinois. They each held a Private Pilot Certificate, and had flight experience ranging from 40 to 150 hours.

The order of presentation of the displays to each subject was different and designed so that differential transfer effects would be cancelled. Each subject started off with a different display type, and moved on to the other displays in a specified sequence.

2.3.2.3 Simulator Experiment Results

The experimental results showed that both attitude presentation and command presentation have an effect on pilot performance, and various aspects of the configuration can have different effects depending upon the circumstances.

The most reliable data were obtained in the Evaluation Task, after the pilots had sufficient time to learn the different display types. In this test, the results support those of previous studies in that the moving airplane configuration was found to be superior to the moving horizon configuration. Both the kinalog and frequency separated displays showed results that were between those of the moving horizon and moving airplane displays.

The experimenters believed that the task load on the pilot was too light to show large differentiation between the display types and suggested a higher workload with performance measures appropriate for the task.

2.3.2.4 Simulator Motion as a Factor

In order to assess the effects of simulator motion on attitude display research, experimenters at the University of Illinois conducted a second series of tests in 1972. In these experiments, the simulator was run without motion to compare with previous results employing motion [6].

Experiments making use of moving horizon, moving airplane, kinalog, and frequency separated displays in compensatory and pursuit modes were conducted with 8 male pilots holding Private Pilot Certificates. In a similar fashion to the original experiments with motion, the evaluation flight tasks consisted of Practice and Evaluation Tasks as described above.

It was found that pilot performance was affected by both the command steering presentation (pursuit or compensatory) and attitude display presentation as previously found. In addition, there was an interaction among command steering presentation, attitude display presentation, and the presence or absence of simulator motion. Overall, performance was superior with the motion system switched on, thus supporting the notion that motion serves to facilitate manual control. It was also found that the advantage of moving airplane and frequency separated displays over moving horizon exists both with and without motion, but more significantly when motion was absent. The results therefore indicate that differences among displays may be smaller when simulator motion is introduced, and the order of merit of various displays may actually change.

It should be noted that the simulator used is obsolete by modern standards, with the motion presentation limited. Therefore, the question still remains as to whether a modern simulator system capable of six degrees-of-freedom would yield results that better represent actual flight. These past experiments do support the notion that simulator motion is an important factor, so additional realism in motion might be expected to lead to more accurate results.

2.3.3 Flight Experiments

As a follow-on to the simulator research, flight experiments were carried out to verify the results in a real-life situation. This was done mainly to allow comparisons with the previously acquired simulator results, since there were strong indications that motion is a significant factor in pilot performance [7].

The equipment used for the flight experiments was a Beechcraft C-45H flying laboratory. The flight tasks were designed to resemble as much as possible the simulator experiments, so that results between the two could be compared. The significant changes made were: (1) the use of non-pilot Naval ROTC students for more consistency between subjects, (2) additional flight tasks were developed involving spatial disorientation, and (3) an inadvertent inconsistency of the pitch presentation in the pursuit frequency separated display was fixed. The actual attitude indicator display was the same system used in the simulator experiments. Instrument flight conditions were simulated in the cockpit by covering the cockpit windows with orange Plexiglas, while the subjects wore blue goggles.

2.3.3.1 Experimentation Method

The subjects were first asked to fly the Evaluation Task (a command flight task) for each display type, in the same fashion as the simulator tests. However, two additional tasks were then added to emphasize the use of visually displayed attitude information in the presence of conflicting physical motion cues.

The first was a disturbed attitude tracking task that required subjects to compensate for displayed attitude perturbations. These perturbations were generated by a band-limited Gaussian noise signal summed with the actual bank attitude signal such that they existed on the display only, and conflicted with actual physical sensations. The second task required subjects to recover from a discrete unusual attitude set-up by the accompanying flight instructor while the subject had his eyes closed. The discrete unusual attitude recovery tasks were conducted using only the moving horizon, moving airplane, and frequency separated displays.

An additional observation was also made in these flight experiments. Throughout the command flight task, and the disturbed attitude tracking task, the subjects were asked to constantly tap on a switch attached to the flight yoke at a consistent comfortable rate. This observation was aimed to serve as an indication of the pilot's mental load, since the ability to multi-task is greatly affected by the amount of concentration required to perform the primary flight task.

2.3.3.2 Experimentation Results

In flight, the moving horizon display and the frequency separated display yielded similar overall tracking performance, with both being superior to the moving airplane display and the kinalog display.

Although the kinalog display is similar to the frequency separated display, its effect was quite different from the frequency separated display that indicates aileron position. The kinalog display failed to yield better tracking, and was also reported to be confusing and even nauseating.

Contrary to numerous simulator test results, including Johnson's 1971 experiments, the moving airplane display yielded consistently worse attitude tracking than either the moving horizon or the frequency separated display. A possible reason for this is differential transfer effects since a disproportionate amount of practice was received on what were basically moving horizon presentations. Even the frequency separated display appears as moving horizon for much of the time. In order to verify or dispute this, further experimentation is necessary.

In tests of recovery from unusual attitudes, the most control reversals were made using the conventional moving horizon display. The frequency separated display resulted in slightly fewer errors, while the moving airplane display clearly yielded the least number of control reversals.

From these flight experiments, it was shown that the frequency separated display provides at least equivalent pilot attitude tracking performance as the moving horizon display, while reducing the number of control reversals. It would appear that a frequency separated display is an appropriate compromise between the moving horizon display's superior attitude tracking performance, and the moving airplane display's superior attitude recovery performance.

However, these results have also indicated that there is reason to question the validity of simulator results, in particular those of fixed-base simulators.

2.3.4 Comments

The findings of these experiments are not conclusive, evidenced by the inconsistent results obtained from flight and simulator experiments. NASA research on effects of flight simulator motion further highlights this point [8]. In their study of pilots' performance in tracking tasks, inconsistent results were obtained when experiments were conducted using motionless simulator, simulator with motion, and actual flight. Their findings led to the suggestion that motionless simulators should not be used for testing flight displays, and that even findings in simulators with motion should be accepted with reservation.

Despite significant previous research on the topic, the benefits and problems with using alternative ADI configurations were not conclusively identified. Although the inconsistent results between simulator and actual flight from previous experiments may be discouraging, it should be noted that simulator technology has matured significantly since the 1960's and 1970's. Thus, the current experiment was conducted to test whether modern full-motion simulator systems will generate more accurate results that are consistent with flight.

2.4 Other ADI Concepts

There have been a number of concepts proposed for unconventional attitude indicator displays. These unconventional display concepts attempt to present an artificial horizon that is more like a real horizon under visual flight conditions. That is, the pilot should view the artificial horizon in peripheral vision as opposed to foveal vision (where the pilot must look intentionally at the display). In theory, this would require less concentration from the pilot, and also decrease the likelihood of control reversal by preventing a psychological figure and background conflict.

2.4.1 Malcolm Horizon

An example of a peripheral attitude display is the Malcolm Horizon, developed by Richard Malcolm [9]. This display projects a narrow line of laser light across the instrument panel. The line is gyro-stabilized, and its movements in pitch and roll represent the apparent motion of the actual horizon, thus operating as a conventional "inside-out" attitude indicator. The large area of projection allows the movement of the horizon to be scanned by using peripheral vision without eye-fixation. In addition, the fact that the artificial horizon is very large results in a significantly reduced tendency for the pilot to become confused.

2.4.2 Background Attitude Indicator

Another interesting unconventional display is the background attitude indicator (BAI) developed by researchers at Lockheed, Ft. Worth [10]. The BAI uses only the outer ¾ inch border along the edge of display screens often found in modern glass cockpits (see Figure 2.4.1). It originally consisted of a white horizon line with blue above it to represent positive pitch, and brown below it to represent negative pitch. Thus, the attitude information framed the other mission data on the displays, in essence allowing one screen to perform two functions simultaneously. The BAI was also then extended to three screens, in either "triplet format" or "global format". The triplet format displays three individual and identical indicators (see Figure 2.4.2), while global format joins three horizontally adjacent displays to act as one large BAI (see Figure 2.4.3).

Having shown initial success, work to further enhance the BAI was accomplished by the Wright Laboratory's Cockpit Integration Division. The main focus of the work was to enhance pitch representation since the only attitude information present was solid blue or brown once the horizon line left the instrument's display field. The following elements in various formats were tested: (1) digital readouts of airspeed, altitude, and heading; (2) wing reference lines to provide a reference for recovery; and (3) a ghost horizon consisting of a dashed white line that appears when the true horizon leaves the view. In addition, colour shading, patterns, and pitch lines with numbers were also tested.

In testing, pilot response was positive, with the BAI displays able to aid them in recovering from unusual attitudes. Results showed that a combination of colour shading and patterns (see Figure 2.4.4) was the format that resulted in the quickest initial stick response time. Furthermore, pilots' subjective evaluations highly favoured the global format over the triplet format. This is consistent with the concept of a wide view peripheral type display producing better response and requiring less concentration from the pilot.

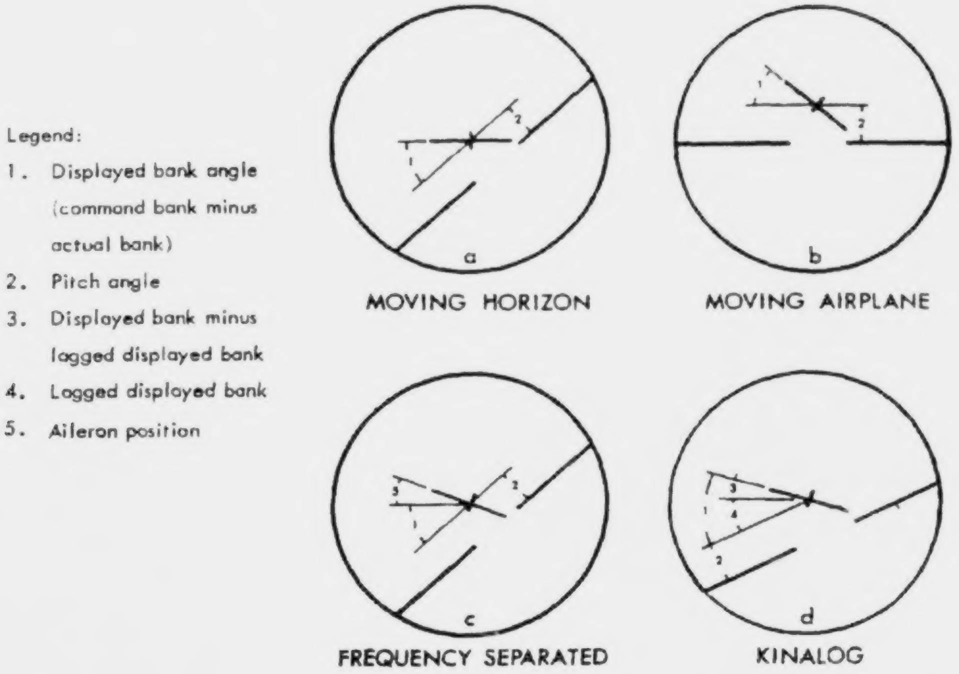
Table 2.3.1

GAT-2 Simulator Limits of Motion

Dimensions	Limits of Motion		
	Position	Velocity	Acceleration
Pitch	$+13^{\circ}$ to -8°	$\pm 13^{\circ}/\text{sec}$	$\pm 100^{\circ}/\text{sec}^2$
Roll	$\pm 13^{\circ}$	$\pm 25^{\circ}/\text{sec}$	$\pm 300^{\circ}/\text{sec}^2$
Vertical Translation	+6 in. to -4.5 in.	N/A	±0.6 g

Figure 2.1.1

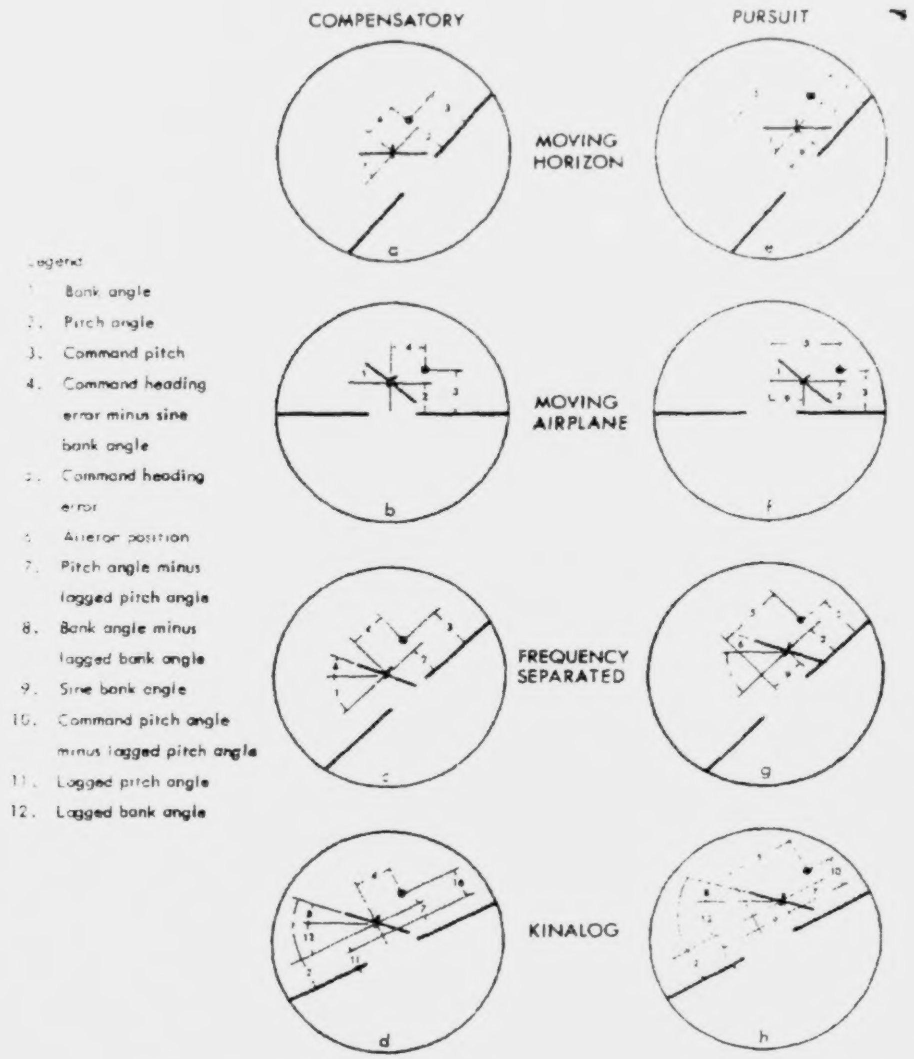
Attitude Director Indicator Types


Legend:
1. Displayed bank angle (command bank minus actual bank)
2. Pitch angle
3. Displayed bank minus lagged displayed bank
4. Lagged displayed bank
5. Aileron position
1
2
a
MOVING HORIZON
1
2
b
MOVING AIRPLANE
3
1
2
c
FREQUENCY SEPARATED
3
4
1
2
d
KINALOG

Reference: Roscoe, S. N. and Williges, R. C., "Motion Relationships in Aircraft Attitude and Guidance Displays. A Flight Experiment", Technical Report ARL-72-32/ONR-72-2, University of Illinois, December 1972

Figure 2.3 1

Experimental Displays for Simulator Trials


COMPENSATORY
PURSUIT
MOVING HORIZON
MOVING AIRPLANE
FREQUENCY SEPARATED
KINALOG
a
e
b
f
c
g
d
h
Legend
1. Bank angle
2. Pitch angle
3. Command pitch
4. Command heading error minus sine bank angle
5. Command heading error
6. Aileron position
7. Pitch angle minus lagged pitch angle
8. Bank angle minus lagged bank angle
9. Sine bank angle
10. Command pitch angle minus lagged pitch angle
11. Lagged pitch angle
12. Lagged bank angle

Reference: Roscoe, S N. and Williges, R. C., "Motion Relationships in Aircraft Attitude and Guidance Displays A Flight Experiment", Technical Report ARL-72-32/ONR-72-2, University of Illinois, December 1972.

Figure 2.4.1

Background Attitude Indicator

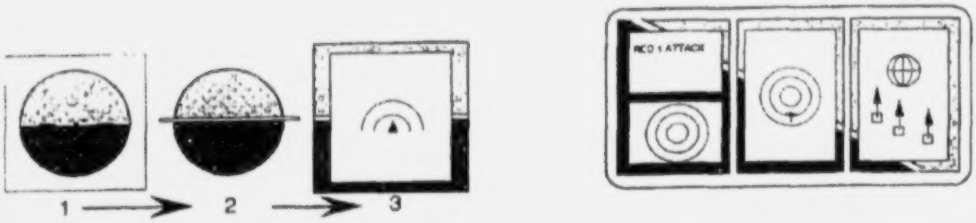

RED 1 ATTACK
1
2
3

Figure 2.4.2

Triplet Format BAI

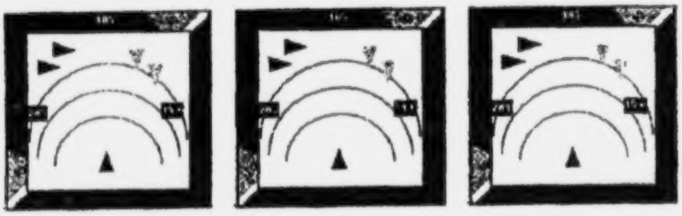


Figure 2.4.3

Global Format BAI

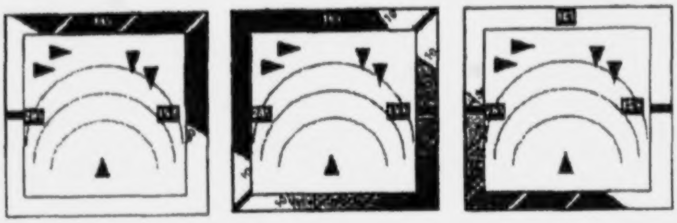
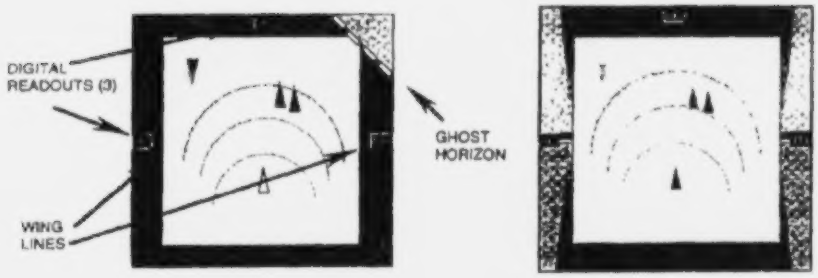


Figure 2 4.4

BAI Shading and Patterns


DIGITAL
READOUTS (3)
GHOST
HORIZON
WING
LINES

Reference (Figures 2.6., 2.7, 2.8, 2.9): Reising, J. M., Solz, T. J. Jr and others, "New Cockpit Technology: Unique Opportunities for the Pilot", SPIE Volume 2219 Cockpit Displays: 1994.

Figure 2.4.1

Background Attitude Indicator

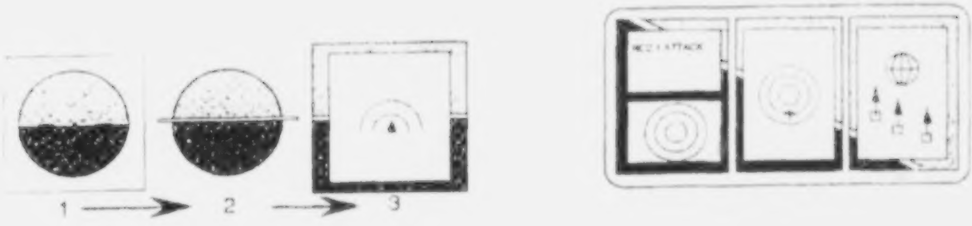


Figure 2.4.2

Triplet Format BAI

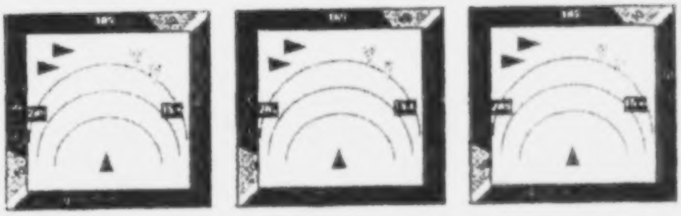


Figure 2.4.3

Global Format BAI

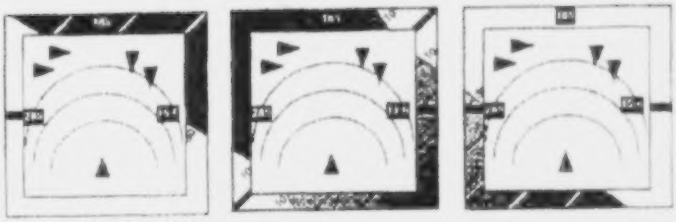
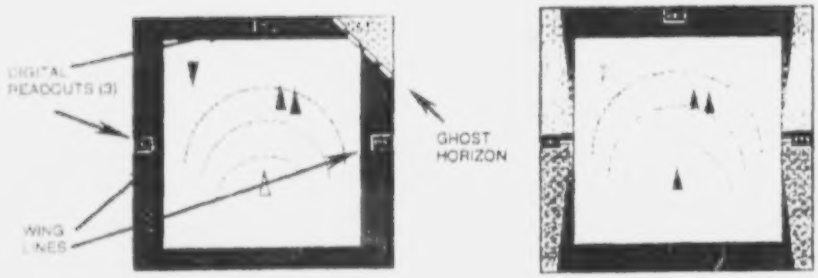


Figure 2.4.4

BAI Shading and Patterns


DIGITAL READOUTS (3)
GHOST HORIZON
WING LINES

Reference (Figures 2.6., 2.7, 2.8, 2.9): Reising, J. M., Solz, T. J. Jr and others, "New Cockpit Technology: Unique Opportunities for the Pilot", SPIE Volume 2219 Cockpit Displays: 1994.

3 Experiment Tasks

Based on the findings of Roscoe's previous experiments as detailed in the previous chapter, the current experiment was restricted to a comparison of conventional moving horizon and frequency separated display ADIs. This project was carried out in the UTIAS Flight Research Simulator configured as a T-33 trainer.

The objective of the experiment was to identify the advantages and disadvantages of the conventional moving horizon display and the frequency separated display. It was also desired to investigate the validity of simulator results for experiments in which human vestibular response plays a significant role. Testing of this aspect was accommodated by performing experiments with simulator motion switched on and off. In order to shorten training time and to ensure that naïve subjects are able to complete the experiments, flight tasks only required lateral (roll) control of the aircraft. All other aspects of flight including altitude, throttle, pitch, and yaw were controlled by autopilot.

This chapter serves to give an overview of the experiment tasks. Details of the simulator configuration used to implement these tasks are given in Chapter 4.

3.1 Primary Piloting Tasks

The purpose of the piloting tasks was to simulate the conditions under which (1) the use of the ADI is essential, and (2) a degree of difficulty in maintaining the attitude of the aircraft is generated. Pilot performance under routine flight that represents the majority of time when such displays are used must be evaluated, along with the ability of pilots to recover from unusual attitudes or deal with unexpected situations. Whether performance in certain situations is improved by sacrificing performance in other situations must be determined.

Except for initial training, all piloting tasks were carried out under instrument flight conditions with the simulator external visual display turned off. The primary flight instruments employed were the ADI and the compass. The aircraft was trimmed to fly straight and level at an airspeed of 337 kts, and the only active flight control was the lateral stick input.

In order to determine pilot performance under both routine flight and unusual attitudes, two categories of flight tasks were evaluated:

- Continuous Events – attitude and heading hold, and navigation exercises
- Discrete Events – recovery from unusual attitudes, response to sudden attitude upsets

3.1.1 Continuous Event Flight Tasks

Continuous event flight tasks consisted of level tracking and heading changes.

3.1.1.1 Level Tracking

The level tracking task consisted of a 90 second flight through turbulence. The piloting task was to maintain wings level and a heading of due north by counteracting the random turbulence in roll. The throttle was fixed, and an altitude hold autopilot maintained a constant height above sea level such that no other pilot intervention was required.

3.1.1.2 Heading Changes

The heading change task was a simple navigation exercise consisting of three commanded turns over a time period of approximately 3 to 4 minutes. Following instructions from the experimenter, the pilot was required to make heading changes using a specified bank angle.

Heading change commands were given in a specific format, a typical example being "Turn right to a heading of zero-three-zero at a bank angle of 20 degrees". Possible bank angle and heading change combinations are given in Table 3.1.1. Each heading change required approximately 30 to 40 seconds, and there was also a 30 second heading tracking task after each turn.

There was no turbulence during this task.

3.1.2 Discrete Event Flight Tasks

The discrete event flight tasks consisted of unusual attitude recoveries and sudden upsets.

3.1.2.1 Unusual Attitude Recovery

The unusual attitude recovery was designed to simulate a situation in which the aircraft has drifted to an orientation away from straight and level. If the movement is gradual and below the human vestibular threshold the pilot may be unaware of the drift and consequently will be surprised to find the aircraft in an unexpected attitude.

To imitate this situation in the simulator, the ADI was blanked out and other instrument displays frozen while the aircraft was placed in a steady 67 degree coordinated banked turn such that the simulator did not generate any motion cues. The ADI was then unblanked and other instruments unfrozen, at which time the pilot was expected to judge the aircraft's attitude from the ADI, and use the flight controls to return the aircraft to straight and level in a timely manner.

No turbulence was present for this task.

3.1.2.2 Sudden Attitude Upset

The sudden attitude upset task was designed to represent a wake vortex encounter. During one out of every 3 level tracking tasks (see Section 3.1.1.1), the aircraft suddenly experienced a large rapid roll rate without warning. The pilot was expected to recover to a wings level attitude using lateral stick input only. The rapid roll rate occurred randomly right or left, and if unchecked caused the aircraft to reach a peak bank angle of 78 degrees. The time in a run at which the upset occurred was randomly selected from 60 to 90 seconds after the start of the level tracking task.

3.2 Secondary Tasks

Secondary tasks are introduced in order to evaluate pilot workload and spare capacity. Secondary tasks should be unobtrusive, such that performance in the primary task is not degraded. The manner in which the secondary task is accomplished should also be consistent among subjects. From previous research using secondary tasks [11], tracking tasks were chosen to best fulfill these requirements. Two tracking tasks were used, one audio and one visual.

Both the audio and visual tracking tasks involved the use of a small joystick controller to maintain a signal at a desired level. As the signal drifted away from the desired level pilot inputs were necessary to cancel the drift. In the audio task, the signal was an audio tone that must be maintained at the desired frequency (or pitch). Pushing forward on the joystick raised the frequency, and pulling back on the joystick lowered the frequency.

For the visual task, a bar graph display was used where the bar rises towards the top or drops towards the bottom, the goal being to maintain the bar in the middle of the column. The polarity of the joystick in this case was set to mimic an aircraft control stick. In other words, pushing forward on the joystick caused the bar to fall, and pulling back raised the bar.

The drift in signal was driven with the output of an unstable first-order linear system (see Section 4.10). The time constant values were chosen to allow similar performance while performing either task, and to also be easy enough that all subjects can handle the task while simultaneously performing the primary flight tasks.

Table 3.1.1

Heading Changes Task Bank Angle/Heading Change Combinations

Bank Angle (degrees)	***Heading Change (degrees)***
20	30
30	30 or 60
40	60 or 90
50	90 or 120

4 Simulator Development

The development of the UTIAS Flight Research Simulator for this experiment was fully described in Reference [12]. The complete MATRIXx code used for this simulation can be found in Appendix A of [12]. The information pertinent to the final configuration used in the experiment is presented in this chapter.

The UTIAS Flight Research Simulator consists of a generic aircraft cab mounted on a six degrees-of-freedom hexapod motion system (see Figure 4.1). In the present study, the rear-facing station was used, with the out-the-window visual display consisting of a single collimating window box with a 30°V x 40°H field of view. The primary pilot control was a hydraulically loaded centre stick. A small joystick operated by the left hand was also installed on the left hand arm rest for the secondary task. A computer driven digital sound system, and an electronic flight instrument system (EFIS) displayed on a 19" colour display monitor were also employed. Figure 4.2 shows the interior of the simulator.

The visual database used is that for the CFB Gagetown area. This fairly level terrain was suitable for training the subjects to fly the aircraft under visual flight conditions. During all evaluation flights the out-the-window display was turned off to simulate instrument flight conditions. A moving map display (see Figure 4.3) of the Gagetown area was created to aid the experimenter in guiding the subjects to remain within the confines of the database (approximately 80 km x 80 km).

The aircraft modelled was the T-33 trainer jet. Its characteristics are documented in Reference [13].

4.1 Attitude Director Indicator

The simulator was originally configured to employ three different versions of ADI: conventional moving horizon, frequency separated, and kinalog. Since the final experiment used only the first two, only those of interest will be discussed in this document.

The moving horizon and frequency separated displays were described in Chapter 2. In this implementation, only the roll degree-of-freedom of the ADI was employed. Figure 4.1.1 shows the basic symbology common to both ADI types.

4.1.1 Conventional ADI

In a conventional moving horizon ADI the aircraft symbol is fixed relative to the instrument case (or the aircraft itself) and the artificial horizon line moves relative to it. Figure 4.1.2 shows the display representing an aircraft at 40° nose up pitch but having a positive bank angle ϕ_B (rolled to the right).

4.1.2 Frequency Separated ADI

In the frequency separated ADI the artificial horizon line moves in the same manner as in the conventional moving horizon ADI. However, the aircraft symbol is driven by the pilot's inputs such that it rolls with an angle proportional to the aircraft's aileron deflection. The aircraft symbol roll angle is given by

$$\phi_s = K_S \delta_a \tag{4.1.1}$$

where δ_a is the aileron deflection. K_s was chosen such that 11.3° of aileron deflection corresponded to a 90° rotation of the aircraft symbol.

Figure 4.1.3 shows the display representing an aircraft at 40° nose up pitch but having a positive bank angle and a positive aileron deflection (commanding a roll to the right).

4.2 Flight Equations

The full nonlinear flight equations were employed in the simulator. They are a slightly modified version of those presented in Section 3.8 of Reference [14] as a MATRIXx module. In keeping with the data available in Reference [13], the rotating subsystems were neglected.

The inputs to the flight equations were the forces $\underline{fB_B}$ and moments $\underline{GB_B}$ described in Section 4.3. The outputs included the aircraft Euler angles $\underline{E_B}$ and rates $\underline{\dot{E}}_B$, the aircraft inertial angular velocity $\underline{\omega B_B}$ and acceleration $\underline{\dot{\omega} B}_B$, inertial velocity $\underline{VB_B}$ and acceleration $\underline{aB}_B$ and the location $\underline{rB}_E$ of the aircraft CG relative to an Earth-fixed reference frame.

The required physical data for the selected T-33 aircraft are presented in Table 4.2.1. This corresponds to Case 6 of Reference [13], which is flight at Mach number 0.55 (TAS of 338 kt) at an altitude of 20,000 ft.

4.3 Forces and Moments

The forces and moments applied to the aircraft were due to gravity, aerodynamics and engine thrust. They were the input to the flight equations of Section 4.2. A linearized model, given as components in the aircraft body-fixed reference frame F_B, was employed based on the stability derivative data presented in Reference [13]. In this simulation, the body axes were almost identical to the stability axes of Reference [15] and therefore assumed as such.

In this development it was assumed that there is no mean wind present. The reference equilibrium flight condition was taken to be straight and level unaccelerated flight at an airspeed of U_{ref}. Thus, in terms of the stability derivatives, the forces $\underline{fB}_B$ and moments $\underline{GB}_B$ were given by the following (using the notation of References [14] and [15]).

$$fB_{xB} = X_u(UB_{xB} - U_{ref}) + X_w UB_{zB} + X_{\delta_e}\delta_e + X_{\delta_t}\delta_t \tag{4.3.1}$$

$$fB_{yB} = Y_v UB_{yB} + Y_{\delta_r}\delta_r \tag{4.3.2}$$

$$fB_{zB} = Z_u(UB_{xB} - U_{ref}) + Z_w UB_{zB} + Z_{\delta_e}\delta_e - MB.g \tag{4.3.3}$$

$$GB_{xB} = L_v UB_{yB} + L_p \omega B_{xB} + L_r \omega B_{zB} + L_{\delta_a}\delta_a + L_{\delta_r}\delta_r \tag{4.3.4}$$

$$\begin{aligned} GB_{yB} = {} & M_u(UB_{xB} - U_{ref}) + M_w UB_{zB} + M_{\dot{w}}\dot{U}B_{zB} \\ & + M_q \omega B_{yB} + M_{\delta_e}\delta_e + M_{\delta_t}\delta_t \end{aligned} \tag{4.3.5}$$

$$GB_{zB} = N_v UB_{yB} + N_p \omega B_B + N_r \omega B_{zB} + N_{\delta_a}\delta_a + N_{\delta_r}\delta_r \tag{4.3.6}$$

In the above, since wind effects were absent, the airspeed $\underline{UB}_B$ is given by

$$\underline{UB}_B = \underline{VB}_B \tag{4.3.7}$$

where the inertial velocity $\underline{VB}_B$ comes from Section 4.2. The control inputs δ_e, δ_a, δ_r and δ_t (elevator angle, aileron angle, rudder angle and throttle setting) are described in Section 4.4.

The stability derivatives used in Reference [13] are indicated here by the prefix 'N' (e.g., NX_u for the X-force due to u). The stability derivatives employed in (4.3.1) to (4.3.6) are then given by:

$$X_u = m_B NX_u \tag{4.3.8}$$

$$X_w = m_B NX_w \tag{4.3.9}$$

$$X_{\delta_e} = m_B NX_{\delta_e} \tag{4.3.10}$$

$$X_{\delta_t} = m_B NX_{\delta_t} \tag{4.3.11}$$

$$Y_v = m_B NY_v \tag{4.3.12}$$

$$Y_{\delta_r} = m_B NY_{\delta_r} U_{ref} \tag{4.3.13}$$

$$Z_u = m_B NZ_u \tag{4.3.14}$$

$$Z_w = m_B NZ_w \tag{4.3.15}$$

$$Z_{\delta_e} = m_B NZ_{\delta_e} \tag{4.3.16}$$

$$L_v = (I_x NL'_B - I_{xz} NN'_B)/U_{ref} \tag{4.3.17}$$

$$L_p = I_x NL'_p - I_{xz} NN'_p \tag{4.3.18}$$

$$L_r = I_x NL'_r - I_{xz} NN'_r \tag{4.3.19}$$

$$L_{\delta_a} = I_x NL'_{\delta_a} - I_{xz} NN'_{\delta_a} \tag{4.3.20}$$

$$L_{\delta_r} = I_x NL'_{\delta_r} - I_{xz} NN'_{\delta_r} \tag{4.3.21}$$

$$M_u = I_y NM_u \tag{4.3.22}$$

$$M_w = I_y NM_w \tag{4.3.23}$$

$$M_{\dot{w}} = I_y NM_{\dot{w}} \tag{4.3.24}$$

$$M_q = I_y NM_q \tag{4.3.25}$$

$$M_{\delta_e} = I_y NM_{\delta_e} \tag{4.3.26}$$

$$M_{\delta_t} = I_y NM_{\delta_t} \tag{4.3.27}$$

$$N_v = (I_z NN'_B - I_{xz} NL'_B)/U_{ref} \tag{4.3.28}$$

$$N_p = I_z NN'_p - I_{xz} NL'_p \tag{4.3.29}$$

$$N_r = I_z NN_r' - I_{xz} NL_r' \tag{4.3.30}$$

$$N_{\delta_a} = I_z NN_{\delta_a}' - I_{xz} NL_{\delta_a}' \tag{4.3.31}$$

$$N_{\delta_r} = I_z NN_{\delta_r}' - I_{xz} NL_{\delta_r}' \tag{4.3.32}$$

In (4.3.5) $\dot{U}B_{zB}$ can be found from (4.3.7)

$$\dot{U}B_{zB} = \dot{V}B_{zB} \tag{4.3.33}$$

where $\dot{V}B_{zB}$ comes from Section 4.2.

The physical data corresponding to Case 6 in Reference [13] for the selected T-33 aircraft are presented in Table 4.3.1. The forces and moments equations were implemented as a MATRIXx module.

The lateral dynamics of the simulated aircraft were characterized by the following eigenvalues:

Dutch Roll	-0.1312 (1/s) ± 1.6389i (rad/s)
Roll	-1.6207 (1/s)
Spiral Mode	-0.0081 (1/s)

From Reference [13] the approximate roll rate transfer function for aileron inputs is given by

$$\frac{\bar{p}}{\bar{\delta}_a} = \frac{11.7}{s+1.66} \quad \text{rad/s/rad} \tag{4.3.34}$$

From the above it can be seen that a good estimate for a roll response time constant would be

$$\begin{aligned} T_{roll} &= 1/1.64 \\ &= 0.61 \text{ s} \end{aligned} \tag{4.3.35}$$

4.4 Flight Control System

The normal configuration of the flight control system (FCS) passes the pilot's inputs on the pilot controls through a scale factor to produce δ_e, δ_a, δ_r and δ_t. This can be seen in Figure 4.4.1. When the altitude hold mode of the FCS is selected the elevator angle δ_e comes from the autopilot instead of the pilot. The normal configuration was selected by setting IFCS to 0 while the altitude hold mode was selected by IFCS = 1. In the normal configuration

$$\delta_e = GAINE \times PC_e \tag{4.4.1}$$

$$\delta_a = GAINA \times PC_a \tag{4.4.2}$$

$$\delta_r = GAINR \times PC_r \tag{4.4.3}$$

$$\delta_t = GAINT \times PC_t \tag{4.4.4}$$

where PC_e, PC_a, PC_r and PC_t are the pilot's control inputs for elevator, aileron, rudder and throttle respectively.

In the altitude hold mode (IFCS = 1) (4.4.1) is replaced by

$$\delta_e = \delta_h \tag{4.4.5}$$

where δ_h is the autopilot output (4.4.9) developed below. In addition, for the present study, the rudder pedals were also rendered inoperative when IFCS = 1. This was carried out to prevent the non-pilot subjects from accidentally generating rudder inputs during the experiments. The simulated aircraft does not require rudder inputs during turn entry and thus the pedals were not required for the planned flying tasks. From Figure 4.4.1 the following equations apply for the altitude hold mode.

$$e_h = h_{ref} - h \tag{4.4.6}$$

where h_{ref} is the desired holding altitude and h is the altitude from Section 4.2.

$$\theta_c = K \times e_h \tag{4.4.7}$$

$$e_\theta = \theta_c - \theta_B \tag{4.4.8}$$

where θ_B is the aircraft pitch angle from Section 4.2.

$$\delta_e = a_0 \int e_\theta dt + a_1 e_\theta + a_2 \dot{e}_\theta \tag{4.4.9}$$

In (4.4.9) $\dot{e}_\theta$ can be found from e_θ where

$$e_\theta = \mathrm{K}(h_{ref} - h) - \theta_B \tag{4.4.10}$$

and from (4.4.10)

$$\dot{e}_\theta = -K\dot{h} - \dot{\theta}_B \tag{4.4.11}$$

where both $\dot{h}$ and $\dot{\theta}_B$ come from Section 4.2.

The flight control system parameters for the selected T-33 aircraft are presented in Table 4.4.1. The flight control system was implemented as a MATRIXx module.

4.5 Disturbance Signals

Simulated turbulence-induced disturbance was a requirement for the level tracking task of this experiment, in which the pilot's task was to control the aircraft bank (and hence heading). In order to provide rolling disturbances, it was decided to create the lateral disturbances by adding suitably selected signals to the pilot's aileron inputs to the flight model in such a manner that he was unaware of the exact source of the disturbances. The longitudinal disturbances were less critical but coupling into the aircraft's lateral response was to be avoided. This was accomplished by adding the longitudinal disturbances directly to the simulator's motion, visual and EFIS systems. Thus the disturbances never entered into the flight equations themselves. As a result of the process described above it follows that the pilot's aileron input that would exactly cancel the roll disturbance to the aircraft would be the negative of the aileron disturbance input. This fact was of benefit in simplifying the analysis of the data gathered during the experiments.

The implementation of the disturbance scheme is shown in Figure 4.5.1. Here MaxVue refers to the image generator employed on the UTIAS Flight Research Simulator. Δh is the altitude disturbance, $\Delta\theta$ is the pitch disturbance and $\Delta\delta_a$ is the aileron disturbance. Each of the three disturbance components was expressed as the sum of 9 sine waves of specified frequency and amplitude with random phasing. This created a zero mean signal and each of the three components can be scaled to produce the desired level of disturbance. Thus

$$\Delta\delta_a = SFA \sum_{i=1}^{9} AMPA(i)\sin(\omega_{ai}t + \phi_{ai}) \tag{4.5.1}$$

$$\Delta\theta = SFP \sum_{i=1}^{9} AMPP(i)\sin(\omega_{pi}t + \phi_{pi}) \tag{4.5.2}$$

$$\Delta h = SFH \sum_{i=1}^{9} AMPH(i)\sin(\omega_{hi}t + \phi_{hi}) \tag{4.5.3}$$

where ϕ_{ai}, ϕ_{pi} and ϕ_{hi} were randomly generated phase shifts and the other 57 parameters were user specified. Table 4.5.1 gives the initial set of values for the above parameters.

The points of input for the disturbances are indicated in Figure 4.5.1. In the case of Δh and $\Delta\theta$, they were inserted into the simulator motion system downstream of the washout algorithm. The height disturbance Δh was so small that there was no need to show it on the cockpit display (EFIS) or on the MaxVue image generator. However the pitch disturbance $\Delta\theta$ can be seen and must be shown visually to the pilot. When it was applied to the cockpit display (EFIS) it was first divided by the washout algorithm scale factor so that the displayed disturbances were scaled in the same manner as the other aircraft produced pitch signals. The MaxVue was fed the same pitch disturbance as the EFIS. The aileron disturbance $\Delta\delta_a$ was added to the pilot's input just before entering the flight equations as δ_a. Thus the pilot did not feel $\Delta\delta_a$ as a control movement.

In applying Δh to the simulator motion system it was decided to ensure that the resulting simulator cab motion due to Δh was always perpendicular to the floor of the cab. This was to prevent coupling between the simulator cab roll attitude and the pilot's sensed motion due to Δh.

A disturbance signal was also needed for the sudden attitude upset task. This task required the aircraft to suddenly respond to the influence of a wake vortex. In the experiment, this was simulated by adding an aileron pulse to the turbulence $\Delta\delta_a$. The waveform of this additional input was selected to give a rapid roll upset producing good simulator motion cues. The amplitude was chosen to produce an upset bank angle of 78 degrees (1.36 rad) in the absence of pilot response.

Figure 4.5.2 shows a time history of the turbulence and the upset signal in a typical sudden attitude upset run. Figure 4.5.3 shows the sudden attitude upset waveform in more detail.

4.6 Simulator Interface

The simulator interface is described in Section 3.13 of Reference [14] as a MATRIXx module. Some minor modifications were implemented in order to allow for compatibility with the fixed-wing configuration of this experiment, and dimensional units. These changes are presented below.

The cockpit display true airspeed was given by

$$\text{INSTTAS} = 0.592\,|\underline{UB}_B| \text{ kts} \tag{4.6.1}$$

Barometric altitude was given by

$$\text{INSTALT} = as\ell \text{ ft} \tag{4.6.2}$$

The rate of climb was given by

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$$\text{INSTROC} = -60\ VB_{zE} \quad \text{fpm} \qquad (4.6.3)$$

4.7 Simulator Motion

Due to the nature of this study, simulator lateral motion quality was very important. The pilot's aileron inputs when performing a manoeuvre or when responding to a disturbance can be strongly influenced by the lateral physical motion cues that he senses in the simulator. These motions consisted of simulator roll and sway. They in turn depended on the simulator motion system washout filters, the simulator reference point selected for matching aircraft motions, and the location of the pilot in the aircraft relative to the CG. Figure 4.7.1 shows the simulator reference point (*SRP*) location relative to the pilot's eyepoint (*E*) and the centroid of the upper simulator frame bearing blocks (*C*). (See Appendix D of Reference [16] for a description of simulator geometry.) The origin of reference frame F_I is at the centroid of the lower simulator frame bearing blocks. Using the vectors in Figure 4.7.1, the location of *SRP* relative to the origin of F_I when the simulator is at rest is given by

$$\underline{S}_{I_{rest}} = \underline{SC}_{I_{rest}} + \underline{rCS}_{I_{rest}} \qquad (4.7.1)$$

where the subscript *rest* indicates the rest state with all simulator actuators at half extension. It should be noted that in the rest state, simulator reference frame F_S is parallel to F_I and hence

$$\underline{rCS}_{I_{rest}} = \underline{rCS}_S \qquad (4.7.2)$$

Thus (4.7.1) can be written out for the rest state, using (4.7.2), as

$$\underline{S}_{I_{rest}} = \underline{SC}_{I_{rest}} + \underline{rCS}_S \qquad (4.7.3)$$

In (4.7.3) $\underline{SC}_{I_{rest}}$ is a fixed vector for a given simulator. $\underline{rCS}_S$ was selectable by the experimenter to suit the application. The most significant impact of the choice of $\underline{rCS}_S$ on the operation of the simulator motion system is in the area of tilt-coordination (see Section 5.2.2 of Reference [16]). The rotations involved in tilt-coordination take place about *SRP*. While tilt-coordination is intended to take place so slowly that its tilt-rate is not detected by the pilot, this is not always achieved. If the offset $\underline{rSE_S}$ (see Figure 4.7.1) is sufficiently large, the tilt motion can also induce linear accelerations at the location of the pilot which defeats the original intent. This can be minimized by moving *SRP* closer to the eyepoint *E*. The downside of doing this is that the further away *SRP* is away from the centroid *C*, the more simulator actuator travel is required to achieve a given tilt, thus reducing the travel available for other simulator motions. A trade-off must be made for each application.

The washout algorithm that runs the motion system requires input parameters specifying the location of the upper frame bearing blocks in terms of $\underline{rCS_S}$ of Figure 4.7.1. In Figure 4.7.2 the *i*-th upper frame bearing block is located at the point BB_i. The washout algorithm uses $\underline{Ai_S}$, the location of the block relative to the simulator reference point *SRP*. From the figure, the required location of the upper bearing blocks is

$$\underline{Ai_S} = \underline{ACi_S} - \underline{rCS_S} \qquad (4.7.4)$$

where $\underline{ACi_S}$ comes from the motion system geometry.

During simulated flight, the signals sent to the motion system depend upon the location of the aircraft reference point *ACRP* relative to the aircraft's CG. This point represents the location in the aircraft whose motion properties are simulated at the *SRP* in the simulator. It is located relative to the pilot's eye point by the vector **dSE** (see Figures 4.7.1 and 4.7.3) such that

$$\underline{dSE_B} = \underline{rSE_S} \qquad (4.7.5)$$

where it has been assumed that the frames F_S and F_B are identically oriented relative to the pilot. The washout algorithm drives the motion system in an attempt to match the simulator motion at the *SRP* with the aircraft motion at the *ACRP*.

In the present project it was found that the best roll motion cues were achieved in the simulator when the *SRP* in the simulator was located at the pilot's eye point and the

ACRP was located on the *x*-axis of the aircraft's F_B. This process removed undesirable lateral sway jerkiness from the simulator motion during rolling maneuvers. From Figure 4.7.3 this means that the *z*-component of **rAS** is given by

$$rAS_{zB} = 0 \tag{4.7.6}$$

The resulting physical data are given in Table 4.7.1. The simulator motion washout algorithm employed is described in Reference [17]. The washout algorithm parameters employed are given in Table 4.7.2. It can be seen that the heave due to aircraft response has been set to zero (*KFZ* = 0). This freed up simulator motion capacity, allowing the lateral scale factors to be increased to unity (*KFY* = *KWP* = 1). The washout filter parameters are further described in Table 4.7.3.

4.8 **Flight Instruments**

The flight instruments consisted of the Electronic Flight Instrument System (EFIS) shown in Figure 4.1.1. From the top left the display showed rate of climb, airspeed, ADI and altitude. Below the ADI were the rate of turn, slip, and compass heading. To the right was a continuously running 60 second timer.

4.9 **Pilot Controls**

Control loading on the primary stick was provided by a McFadden System Inc. Model 292B Universal Variable Digital Cockpit Control Force Loading System. Only the lateral stick characteristics were of interest in this experiment and the selected parameter values representing values at the hand grip are given in Table 4.9.1.

The T-33 simulation was configured such that full scale lateral stick inputs gave an aileron deflection of ±12.43° (±0.217 rad). This determined the maximum control power available to the pilot when attempting a rapid recovery from a roll upset.

The pilot also used a small joystick with the left hand for control of the secondary task. This stick was simply spring loaded.

4.10 Secondary Tasks

The secondary tasks for this project involved the control of an unstable first-order system with no disturbances present. This task was presented as a regulator problem, with the pilot attempting to drive the output back to its reference value. The governing system equation had the transfer function

$$\frac{\bar{o}}{\bar{i}} = K\frac{a}{s-a} \tag{4.10.1}$$

Here i is the pilot's input, o is the system output, the bar on top of a symbol represents the Laplace transform of the symbol, s is the Laplace variable and a is a positive constant. The time constant of the system was given by 1/a seconds, and the time to double amplitude was

$$t_{double} = \frac{0.693}{a} \quad \text{seconds} \tag{4.10.2}$$

The gain K was selected to provide a harmonious response to inputs.

Two versions of the secondary task were employed, an audio version and a visual version. In either case, the output variable is a representation of the error from the desired value.

A pure tone produced by a Yamaha TX81Z tone generator was employed in the audio version for the output variable. The frequency ranged from 734 Hz to 2960 Hz with 127 possible values. The reference frequency was 1480 Hz, and a reference tone of 1 second in length was presented to the pilot at 10 second intervals.

In the visual version, the audio output was turned off and the output variable was displayed in the lower right hand corner of the instrument panel display by a linear display with a moving rectangular symbol (see Figure 4.10.1). Full scale on the visual display corresponded to full scale on the audio output. Note that the scale on the secondary tasks has been normalized in this report to a range of -1 to $+1$ for the display. The parameter a and K in (4.10.1) was selected to create a moderately difficult secondary task which could be kept under control at all times. The times constants for the audio and visual tasks were selected so as to provide similar task difficulty when flying the level tracking task. The selected parameter values are given in Table 4.10.1.

Table 4.2.1

Flight Equations

T-33 Numerical Data

Parameter	**Value**	**Source**
ASLO	selected	selected
G	32.2 ft/s^2	-
IB(1,1)	23801 slug.ft^2	Ref. [13]
IB(2,2)	21101 slug.ft^2	Ref. [13]
IB(3,3)	43802 slug.ft^2	Ref. [13]
IB(1,3)	-480 slug.ft^2	Ref. [13]
MB	425.5 slug	Ref. [13]
PSIBic	selected	selected
RB_Eic(K)	selected	selected
UREF	570 ft/s	Ref. [13]
VB_Ric(K)	[UREF 0 0] ft/s	Ref. [13]

Table 4.3.1

Forces and Moments

T-33 Numerical Data

Parameter	**Value**	
NLPD	-7.42	1/s^{2}
NLPDA	11.7	1/s^{2}
NLPDR	1.39	1/s^{2}
NLPP	-1.56	1/s
NLPR	0.256	1/s
NMDE	-14.2	1/s^{2}
NMDT	0.948×10^{-6}	1/s^{2}
NMQ	-0.981	1/s
NMW	-0.0157	1/s
NMWD	-0.000541	1/ft.s
NNPD	2.60	1/s^{2}
NNPDA	0.121	1/s^{2}
NNPDR	-3.21	1/s^{2}
NNPP	-0.0383	1/s
NNPR	-0.204	1/s
NXDE	0.5	ft/rad.s^{2}
NXDT	0.00235	ft/s^{2}
NXU	-0.00735	1/s
NXW	0.0391	1/s
NYDR	0.0363	1/s
NYV	-0.128	1/s
NZDE	-40.9	ft/rad.s^{2}
NZU	-0.107	1/s
NZW	-1.25	1/s

Table 4.4.1

Flight Control System

T-33 Numerical Data

Parameter	**Value**	
A0	-0.5	s
A1	-0.5	
A2	-0.5	1/s
GAINA	0.0383	rad/in
GAINE	-0.0192	rad/in
GAINR	-0.0222	rad/in
GAINT	0	
HREF	1000	ft
K	0.0004	rad/ft

Table 4.5.1

Disturbance Parameters

SFA	0.01 rad	ω_{ai} (Hz)	0.0748
SFH	0.10 ft		0.1114
SFP	0.01 rad		0.1846
			0.296
AMPA(i)	1		0.5554
	1		1.0313
	1		1.7777
	0.5		2.2218
	0.2		2.9634
	0.05		
	0.025	ω_{hi} (Hz)	0.5
	0.015		0.7
	0.01		1.1
			1.3
AMPH(i)	0.1592		1.7
	0.1137		2.2
	0.0723		2.4
	0.0612		2.6
	0.0187		2.8
	0.0036		
	0.0016	ω_{pi} (Hz)	1
	0.0009		1
	0.0006		1
			0.5
AMPP(i)	1		0.2
	1		0.05
	1		0.025
	0.5		0.015
	0.2		0.01
	0.05		
	0.025		
	0.015		
	0.01		

Table 4.7.1

Data for Simulator Motion

$\underline{rCS}_S$	$[1.02 \quad 0.51 \quad -1.86]^T$	m
$\underline{rAS}_B$	$[0.945 \quad 0 \quad 0]^T$	m

Table 4.7.2

Washout Algorithm Parameters

KFX	0 5	KFY	1	KFZ	0		
KWQ	0 5	KWP	1	KWR	0 5		
GX1	0	GY1	0	GZ1	0	GPSI	0
GX2	0	GY2	0	GZ2	0		
GX3	0	GY3	0	GZ3	0		
GX4	0	GY4	0	GZ4	0		
PX1	1	PY1	1	PZ1	1	PPSI	0.5
PX2	6.25	PY2	25	PZ2	8.2		
PX3	5	PY3	10	PZ3	17 6		
PX4	1	PY4	1	PZ4	3.2		
KX1	25	KY1	9	KPSI1	0		
KX2	10	KY2	7.5	KPSI2	1		
KX3	1	KY3	10				
WX0	0	WY0	0	WZ0	0	WPSI0	0
WX1	0	WY1	0	WZ1	0	WPSI1	0
WX2	0	WY2	0	WZ2	0	WPSI2	0
WX3	0	WY3	0	WZ3	0	WPSI3	0
WX4	0	WY4	0	WZ4	0		
WX5	0	WY5	0	WZ5	0		
WX6	0	WY6	0	WZ6	0		
WX7	0	WY7	0				
WX8	0	WY8	0				
WX9	0	WY9	0				
PHIDMAX	0.02	THEDTMAX	0.03424				
RCSS(1)	1.02	RCSS(2)	0.51	RCSS(3)	-1.86		

WFADOUT 3.14

NFADIN 200

AAIS(3,6)	SSIIN(3):
1 4665, 0.0953,0 ,	0 ,0..-1 8198
1 4665,-0.0953,0.	
-0.6507, -1 3176,0.,	
-0 8157,-1 2224,0	
-0 8157,1.2224, 0.,	
-0 6507, 1.3176, 0.	

Table 4.7.3

Washout Parameter Definitions

Symbol	Definition
N	System order
K_{fx}	X-input scaling
K_{fy}	Y-input scaling
K_{fz}	Z-input scaling
$K_{\omega p}$	p-input scaling
$K_{\omega q}$	q-input scaling
$K_{\omega r}$	r-input scaling
P_{x1}	X-high-pass gain
P_{x2}	X-high-pass ω_n^2
P_{x3}	X-high-pass $2\zeta\omega_n$
P_{x4}	q-high-pass gain
K_{x1}	X-low-pass numerator and X-low pass ω_n^2
K_{x2}	X-low-pass $2\zeta\omega_n$
K_{x3}	q-high-pass ω_n
G_{x1}	Steepest descent slope on P_{x1}
G_{x2}	Steepest descent slope on P_{x2}
G_{x3}	Steepest descent slope on P_{x3}
G_{x4}	Steepest descent slope on P_{x4}
W_{x0}	Weight on X-acceleration error
Wx1	Weight on θ-velocity error
W_{x2}	Weight on simulator X-velocity
W_{x3}	Weight on simulator X-displacement
W_{x4}	Weight on simulator θ-velocity

Continued...

Table 4.7.3

Washout Parameter Definitions (continued)

Symbol	Definition
W_{x5}	Weight on simulator θ-displacement
W_{x6}	Weight on P_{x1} return-to-initial
W_{x7}	Weight on P_{x2} return-to-initial
W_{x8}	Weight on P_{x3} return-to-initial
W_{x9}	Weight on P_{x4} return-to-initial
P_{y1}	Y-high-pass gain
P_{y2}	Y-high-pass ω_n^2
P_{y3}	Y-high-pass $2\zeta\omega_n$
P_{y4}	p-high-pass gain
K_{y1}	Y-low-pass numerator and Y-low-pass ω_n^2
K_{y2}	Y-low-pass $2\zeta\omega_n$
K_{y3}	p-high-pass ω_n
G_{y1}	Steepest descent slope on P_{y1}
G_{y2}	Steepest descent slope on P_{y2}
G_{y3}	Steepest descent on P_{y3}
G_{y4}	Steepest descent slope on P_{y4}
W_{y0}	Weight on Y-acceleration error
W_{y1}	Weight on ϕ-velocity error
W_{y2}	Weight on simulator Y-velocity
W_{y3}	Weight on simulator Y-displacement
W_{y4}	Weight on simulator ϕ-velocity
W_{y5}	Weight on simulator ϕ-displacement
W_{y6}	Weight on P_{y1} return-to-initial
W_{y7}	Weight on P_{y2} return-to-initial

Continued...

Table 4.7.3

Washout Parameter Definitions (continued)

Symbol	Definition
W_{y8}	Weight on P_{y3} return-to-initial
W_{y9}	Weight on P_{y4} return-to-initial
P_{z1}	Z-high-pass gain
P_{z2}	Z-high-pass $2\zeta\omega_n + \omega_2$
P_{z3}	Z-high-pass $\omega_n^2 + 2\zeta\omega_n\omega_2$
P_{z4}	Z-high-pass $\omega_n^2\omega_2$
G_{z1}	Steepest descent slope on P_{z1}
G_{z2}	Steepest descent slope on P_{z2}
G_{z3}	Steepest descent slope on P_{z3}
G_{z4}	Steepest descent slope on P_{z4}
W_{z0}	Weight on Z-acceleration error
W_{z1}	Weight on simulator Y-velocity
W_{z2}	Weight on simulator Y-displacement
W_{z3}	Weight on P_{z1} return-to-initial
W_{z4}	Weight on P_{z2} return-to-initial
W_{z5}	Weight on P_{z3} return-to-initial
W_{z6}	Weight on P_{z4} return-to-initial
P_{ψ}	r-high-pass gain
$K_{\psi 1}$	r-high-pass ω_n^2
$K_{\psi 2}$	r-high-pass $2\zeta\omega_n$ or ω_n when $K_{\psi 1} = 0$
G_{ψ}	Steepest descent slope on P_{ψ}
$W_{\psi 0}$	Weight on ψ-velocity error
$W_{\psi 1}$	Weight on simulator ψ-velocity

Continued...

Table 4.7.3

Washout Parameter Definitions (continued)

Symbol	Definition
$W_{\psi 2}$	Weight on simulator ψ-displacement
$W_{\psi 3}$	Weight on simulator P_{ψ}-return-to-initial
$\dot{\theta}_{\text{tilt max}}$	pitch tilt rate limit
$\dot{\phi}_{\text{tilt max}}$	roll tilt rate limit

Table 4.9.1

Lateral Stick Characteristics

Maximum Displacement	± 7.2 in
Lateral Inertia	6.5 lbm
Lateral Spring Gradient	0.68 lb/in
Lateral Viscous Damping	0.196 lb-sec/in
Breakout Force	1.5 lb
Breakout Deflection	0.14 in

Table 4.10.1

Secondary Task Parameters

Parameter	**Audio**	**Visual**
a s^{-1}	0.250	0.333
1/a s	4	3
t_{double} s	2.77	2.08
$K\ \frac{\%\ full\ scale}{\%\ full\ scale}$	0.05	0.05

Figure 4.1

Exterior of UTIAS Flight Research Simulator

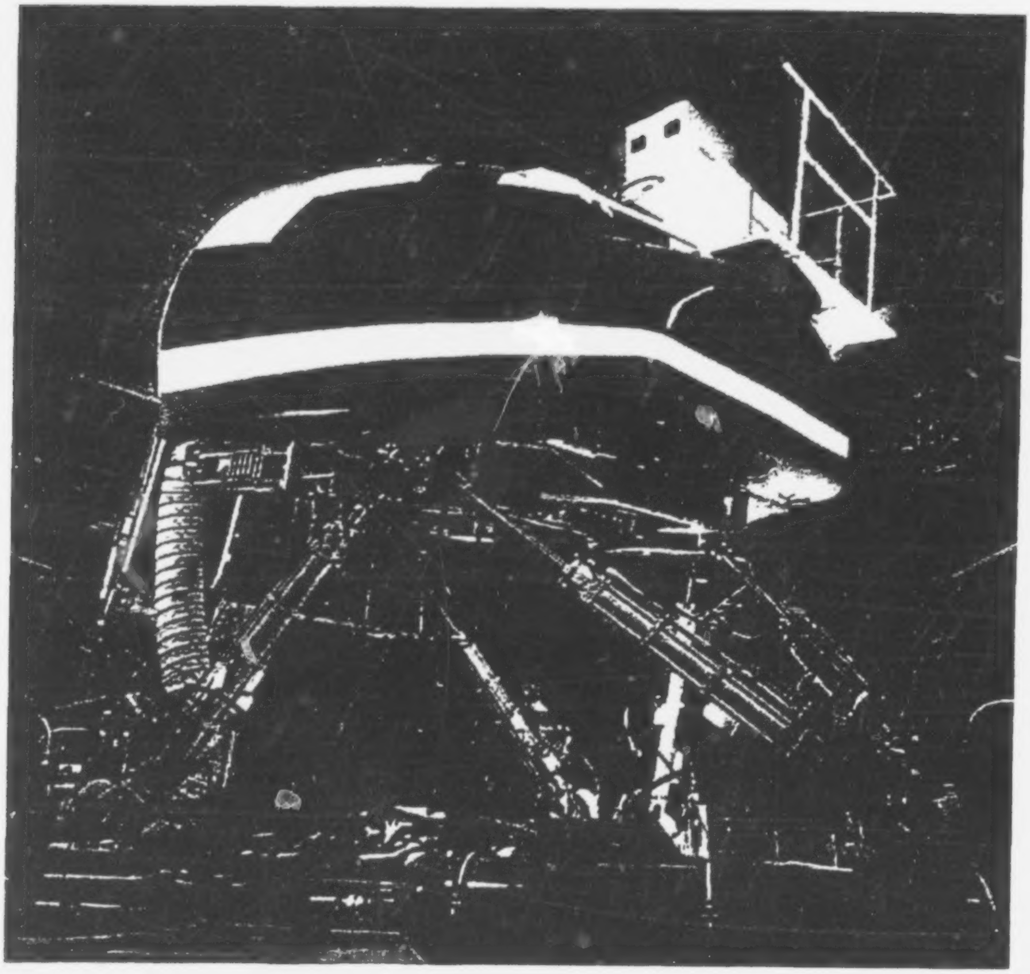


Figure 4.2

Interior of UTIAS Flight Research Simulator

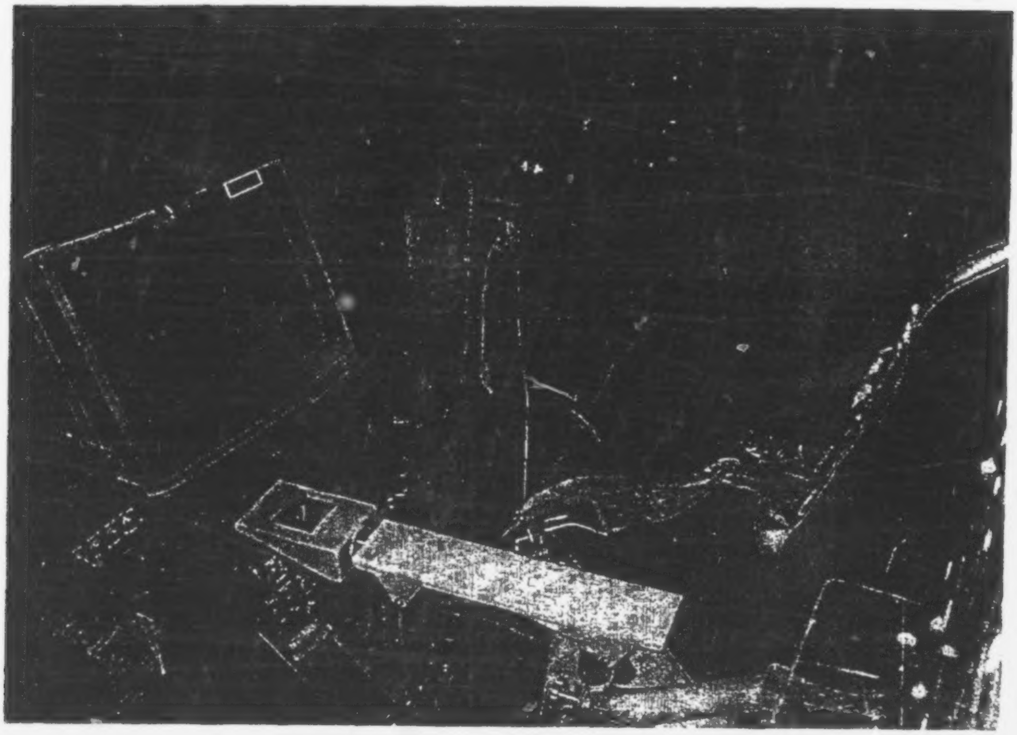


Figure 4.3

Experimenter's Moving Map Display

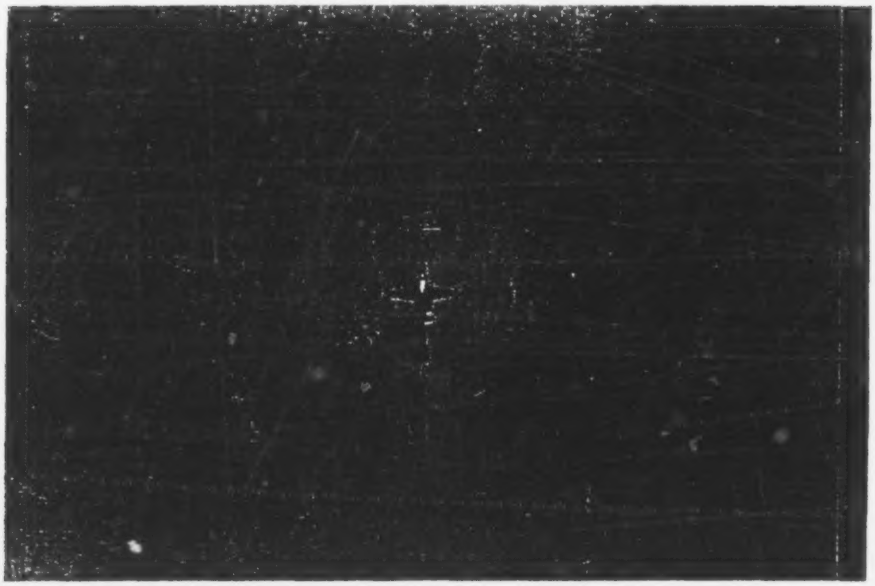


Figure 4.1.1

ADI Symbology

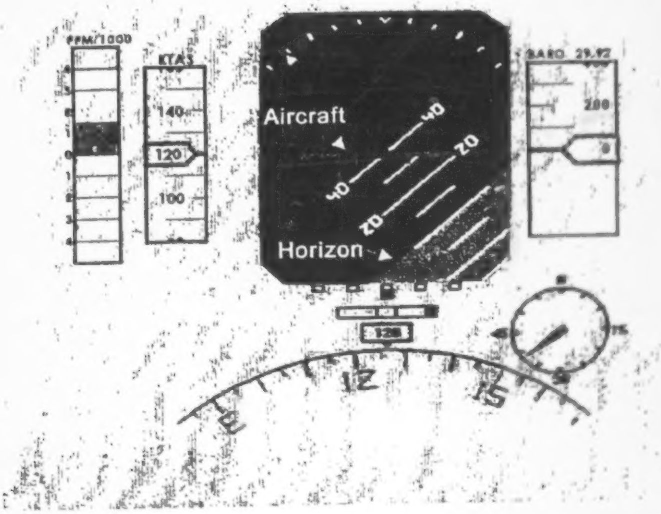

FPM/1000
KTAS
140
120
100
Aircraft
Horizon
40
20
40
20
BARO 29.92
200
0
128
E
12
15

Figure 4.1.2

Conventional ADI

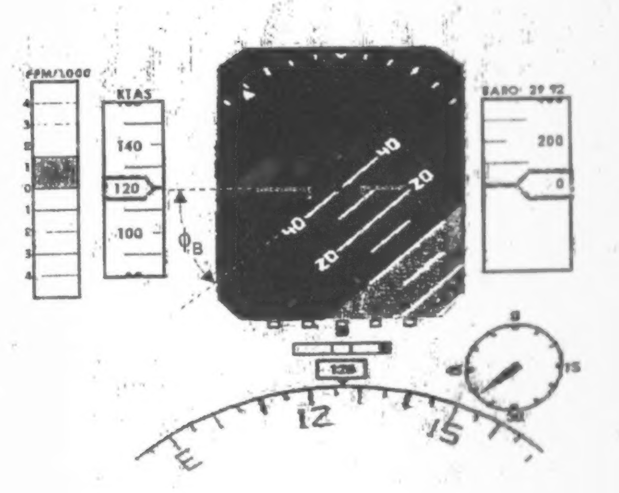

FPM/1000
KTAS
140
120
100
ϕ_B
40
20
40
20
BARO 29.92
200
0
128
E
12
15

Figure 4.1.3

Frequency Separated Display ADI

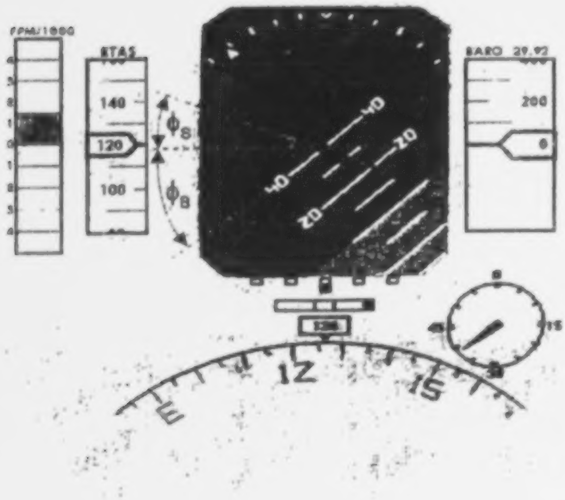

FPM/1000
KTAS
140
120
100
ϕ_S
ϕ_B
40
20
40
20
BARO 29.92
200
0
E
12
15

Figure 4.1.1

ADI Symbology

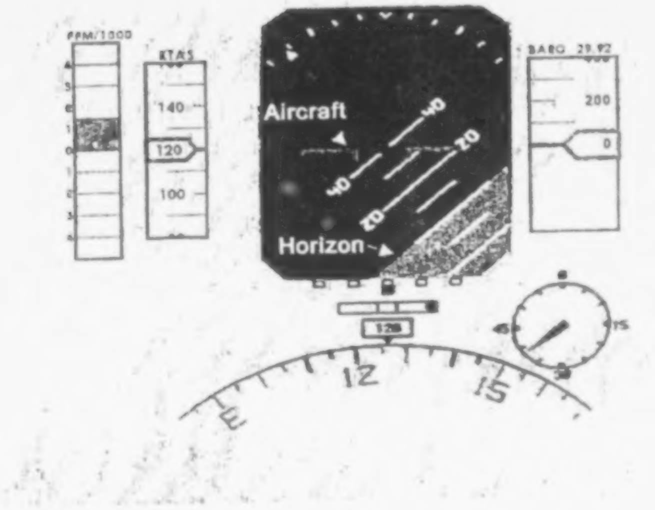

FPM/1000
KTAS
140
120
100
Aircraft
Horizon
40
20
20
40
BARO 29.92
200
0
120
12
15
E

Figure 4.1.2

Conventional ADI

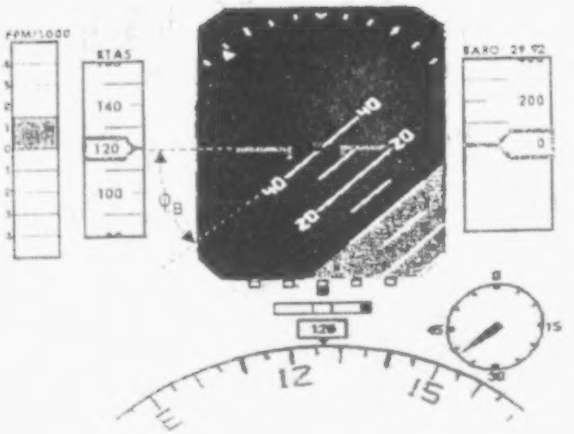

FPM/1000
KTAS
140
120
100
ϕ_B
40
20
20
40
BARO 29.92
200
0
120
12
15
E

Figure 4.1.3

Frequency Separated Display ADI

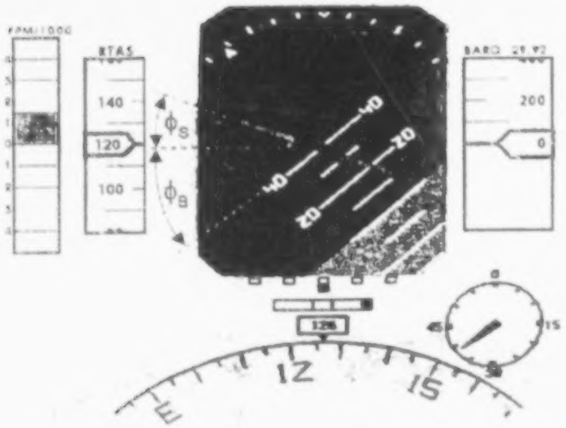
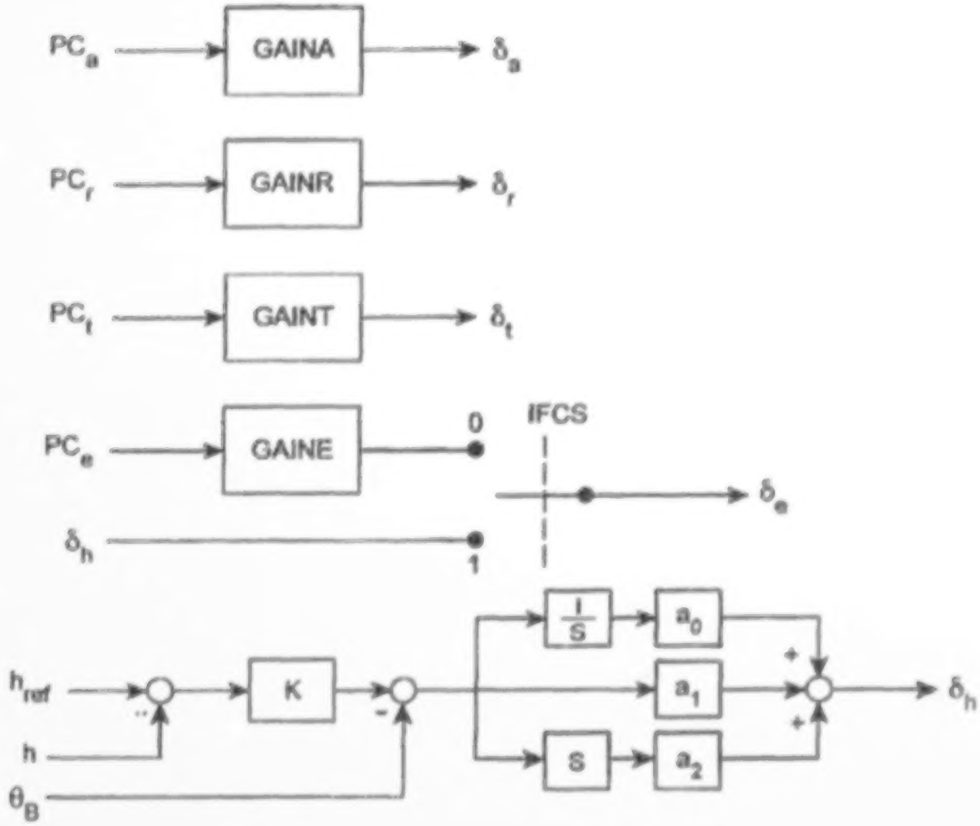

FPM/1000
KTAS
140
120
100
ϕ_S
ϕ_B
40
20
40
20
BARO 29.92
200
0
126
E
12
15
0
15
45

Figure 4.4.1

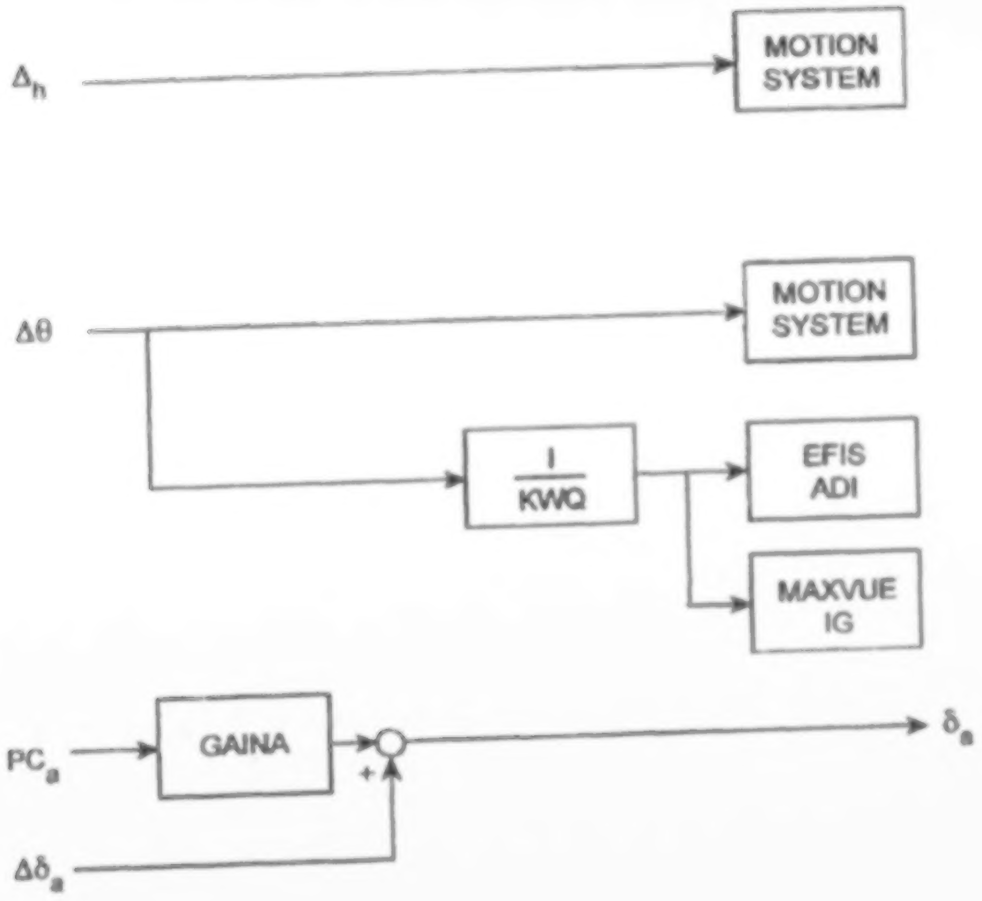
Flight Control System


PC_a
GAINA
δ_a
PC_r
GAINR
δ_r
PC_t
GAINT
δ_t
PC_e
GAINE
0
IFCS
δ_e
δ_h
1
h_{ref}
h
θ_B
-
K
-
$\frac{1}{s}$
a_0
a_1
s
a_2
+
+
δ_h

Reference Reid, L. D., Lan, J. K. Y., Graf W. O., and Haycock B. C., "The Development of a Simulator for ADI Studies", Report for DCIEM Contract W7711-007640/001/TOR, 2000.

Figure 4.5.1

Disturbance Signals


Δ_h
MOTION SYSTEM
$\Delta\theta$
MOTION SYSTEM
1
KWQ
EFIS ADI
MAXVUE IG
PC_a
GAINA
+
δ_a
$\Delta\delta_a$

Reference. Reid, L. D., Lan, J. K. Y., Graf W. O., and Haycock B. C., "The Development of a Simulator for ADI Studies", Report for DCIEM Contract W7711-007640/001/TOR, 2000.

Figure 4.5.2

Time History of Turbulence and Upset Signal in Sudden Attitude Upset Run

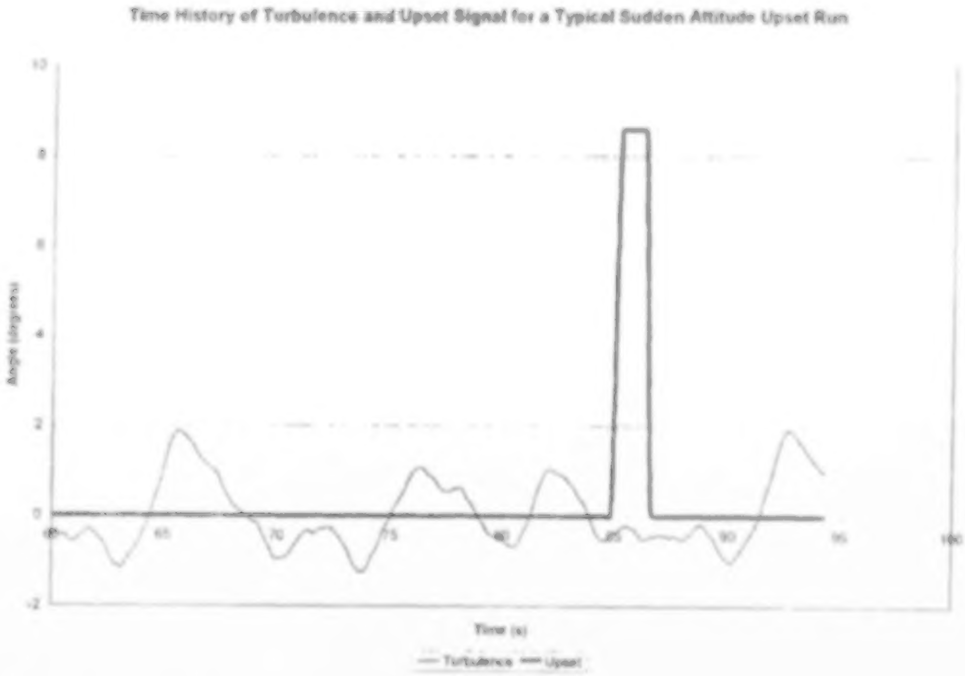


Figure 4.5.3

Upset Signal Waveform for Sudden Attitude Upset Run

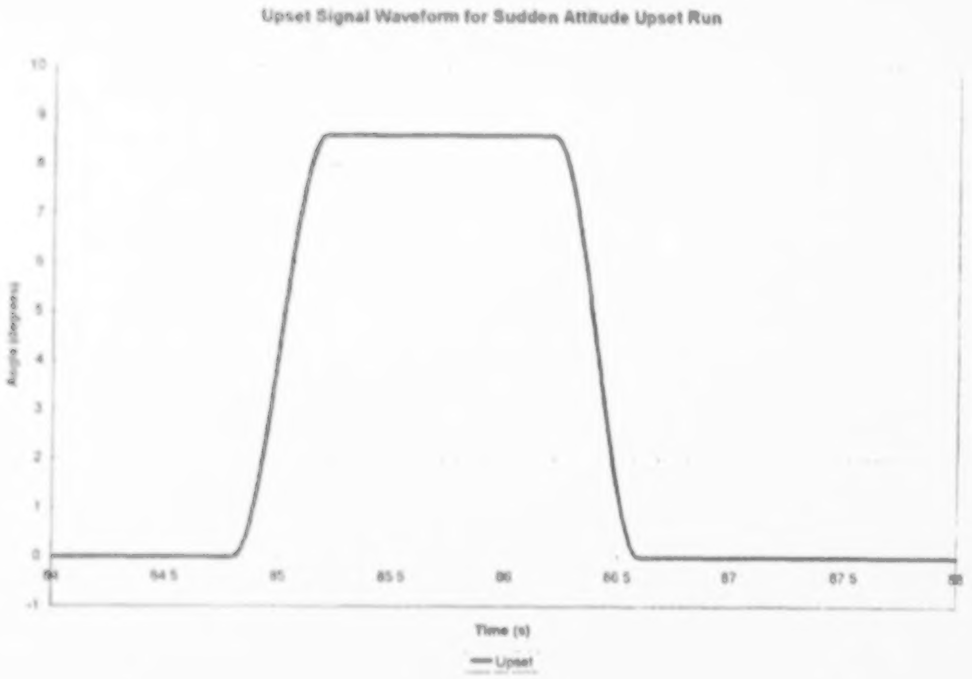
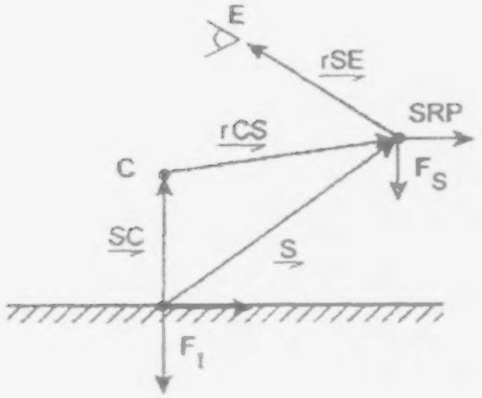


Figure 4.7.1

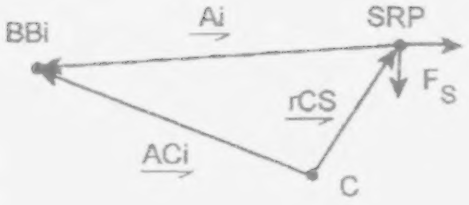
Simulator Motion System Geometry



Reference Reid, L. D., Lan, J. K. Y., Graf W. O., and Haycock B. C., "The Development of a Simulator for ADI Studies", Report for DCIEM Contract W7711-007640/001/TOR, 2000

Figure 4.7.2

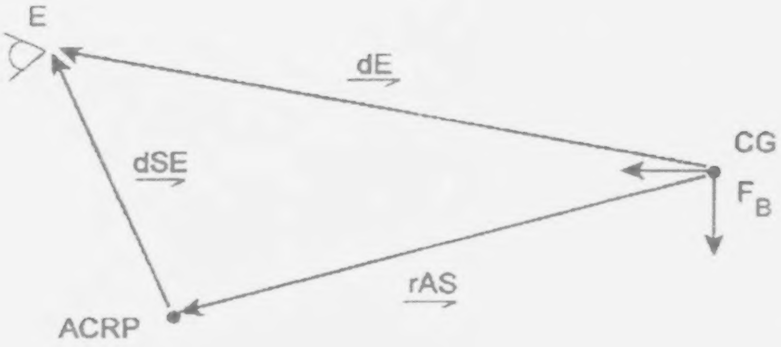
Simulator Upper Bearing Block



Reference: Reid, L. D., Lan, J. K. Y., Graf W. O., and Haycock B. C., "The Development of a Simulator for ADI Studies", Report for DCIEM Contract W7711-007640/001/TOR, 2000

Figure 4.7.3

Aircraft Geometry


E
dE
CG
dSE
F_B
rAS
ACRP

Reference: Reid, L. D., Lan, J. K. Y., Graf W. O., and Haycock B. C., "The Development of a Simulator for ADI Studies", Report for DCIEM Contract W7711-007640/001/TOR, 2000.

Figure 4.10.1

Pilot's Instrument Panel

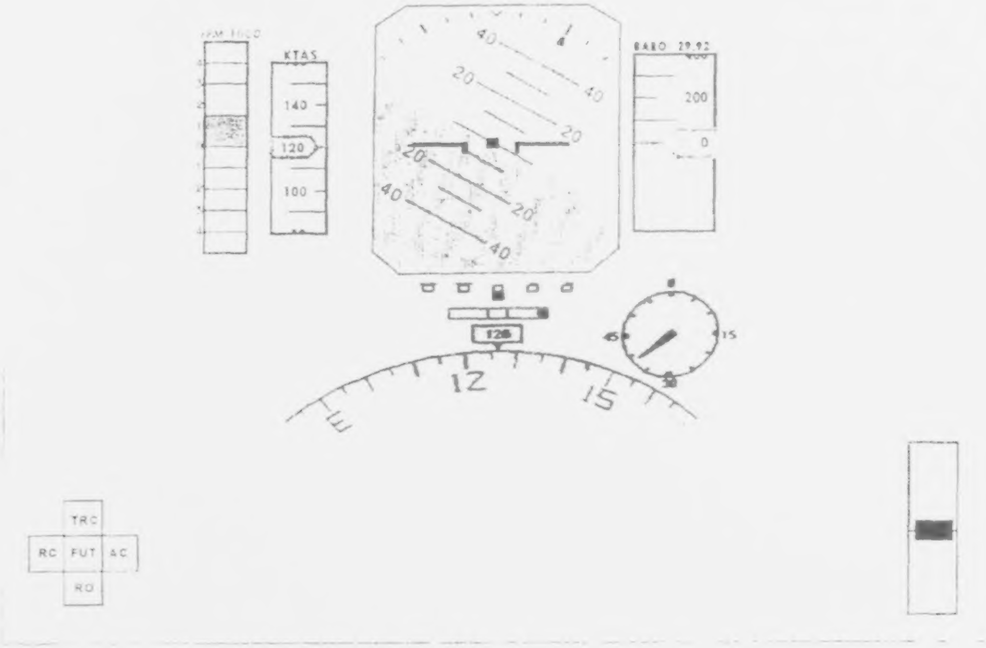
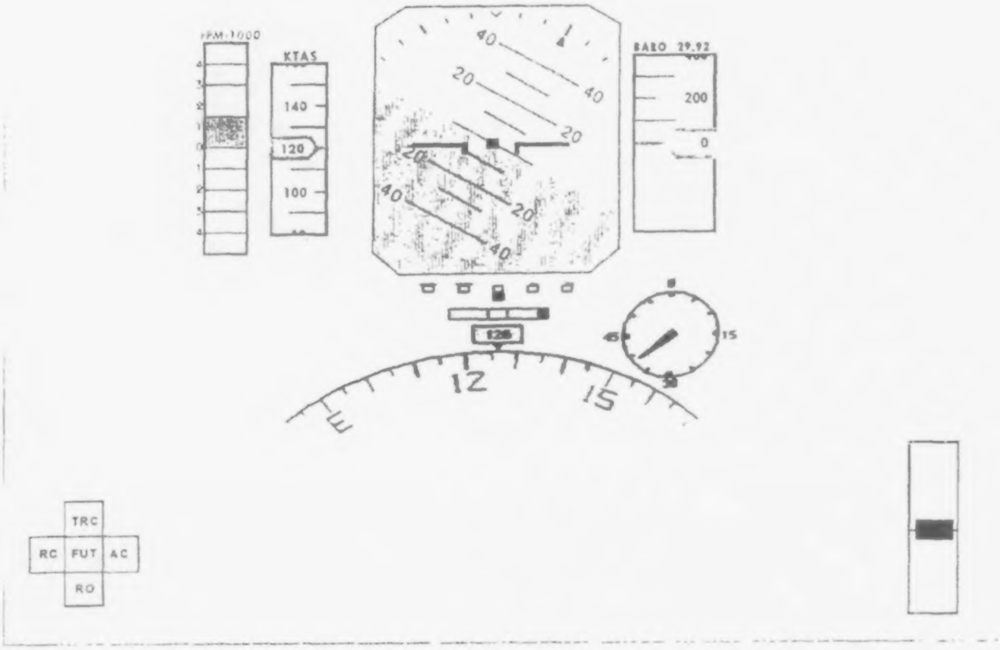

KTAS
140
120
100
40
20
20
40
BARO 29.92
200
0
128
15
12
15
E
TRC
RC
FUT
AC
RD

Figure 4.10.1

Pilot's Instrument Panel


FPM-1000
KTAS
140
120
100
40
20
40
20
20
40
20
40
BARO 29.92
200
0
126
45
15
12
15
E
TRC
RC
FUT
AC
RO

5 Conducting the Experiment

As stated previously, the purpose of this experiment was to study the pilot performance while using the Frequency Separated ADI relative to a conventional moving horizon ADI display. Care was taken in the planning of the experiment to achieve this goal while minimizing bias and secondary effects. Subject selection and scheduling were important considerations. The training process and the conduct of the experiments were also considered. This section details how the experiment was organized and conducted.

5.1 Subject Selection

Simulator test subjects were all persons with no flight experience involving ADIs, including simulator training. This was to prevent bias through previous exposure to conventional moving horizon ADI displays. Since naïve subjects are expected to perform with less consistency compared with trained pilots, a decision was made to include a relatively large number of test subjects.

A total of 25 subjects participated in the study, with 24 successfully completing the experiment. One subject elected to withdraw from the study after failure to complete initial training. The successful test subjects consisted of 4 female and 20 male candidates with ages ranging from 20 to 29 years. The majority were University of Toronto undergraduate and graduate aerospace students. They were paid $300 upon completion of the study.

5.2 Testing Order

The order of testing and exposure to the different types of ADIs may play a significant role in performance. Transfer effects of switching from one ADI to another, as well as between motion and no motion, must also be taken into account. As such, test subjects were split into four basic groups with their designation representing their starting configuration:

- HN – moving horizon ADI, no motion

- HM – moving horizon ADI, motion
- FN – frequency separated ADI, no motion
- FM – frequency separated ADI, motion

From their starting configuration, the subjects switch to other motion/ADI combinations until all four major blocks were completed. The switches were designed such that there was only one type of switch at any time; that is, a subject switching ADI displays would not at the same time switch between motion and no motion, and vice versa. Refer to Table 5.2.1 for the Simulator Experiment Test Matrix.

5.3 Subject Schedule

Except for the first four subjects (one from each of the four starting blocks), each subject required approximately 14.5 hours on-site to complete the study. This consisted of both time in and out of the simulator. A sample general schedule for one subject is given in Appendix A. Subjects typically completed the study on two days, usually within one week.

The first four subjects completed test sessions that were twice the length of the consequent subjects. Each session consisted of a set of runs identical in structures to those given in Appendix A, and then another set of runs in the same structure following a five minute rest. These subjects required approximately 26 hours on-site, spread over four days.

It was found that the original schedule demanded too much time and thus after the first four subjects the schedule was shortened. The decision to reduce the time per subject as opposed to reducing the number of subjects was based on two reasons. The first reason was that the time demand per subject was too great, and it was difficult for students with busy schedules to fulfill the time requirements. The second reason is that since we were using non-pilot subjects, less consistency in performance was expected among subjects and therefore a larger number of subjects might produce better results overall. The flight tasks were found to be simple enough such that the shortened schedule was sufficient for subjects to learn to use each ADI display type to a satisfactory level of performance.

The sample detailed schedule in Appendix A indicates the actual list of runs in each session. The detailed schedule was computer generated for random ordering of runs with the following constraints:

- The structure of each session is constant, consisting of alternating level tracking and heading changes, and ending with two unusual attitude recoveries.
- Each subject completes the same number of left and right unusual attitude recoveries and sudden upsets.
- The sudden upset occurs randomly in either the second or third level tracking of each session.
- Each subject completes each Turn Type (see Appendix H) once in each major block (HN, HM, FN or FM).

The computer code for the random schedule generator, written in Turing, is given in Appendix B.

5.4 Briefing Documents

After confirming participation, each test subject was provided with a copy of the Pilot Briefing Document as contained in Appendix C. This material gave an overview of the experiment that explained the objectives of the study as well as tasks to be performed by the pilot. Also contained were the flight simulator safety procedures and the test subject consent form. No details of the ADIs were given in the document in order to avoid bias.

Appendix D contains the ADI briefing notes used by the experimenter to brief each subject on the ADI display type just prior to use. This ensured that for their first exposure to production runs, each subject only knew the details concerning either the moving horizon or the frequency separated display ADI.

5.5 Training

As indicated in the general schedule in Appendix A, each subject was allotted time for several introduction and training tasks. The total time spent on training each subject was approximately 2 hours. From subjective observation of subject performance by the experimenter, this was found to be adequate in preparation for the tasks performed in production runs of the study.

Initial training lasted approximately one hour and included a review of the Pilot Briefing Document as well as a safety and equipment demonstration prior to entering the simulator. Simulator motion was switched off, and the subjects flew the simulator under VFR conditions at an altitude of 1000 feet and a speed of 337 knots with the ADI blanked off. By learning to fly using only visual cues provided by the out-the-window scenery, the subjects learned to fly the simulator without any exposure to a particular ADI. The subjects received training in both the flying and secondary tasks. Details of the initial training are contained in the Secondary Task Training and Simulator Flight Training sections of Appendix E.

Exposure to the simulator motion cues was received by each subject immediately prior to their first production run involving motion. The motion training session was very similar to initial training except that simulator motion was switched on. This session lasted about one half hour, the details of which are provided in the Motion Training section of Appendix E.

Besides simulator training, each subject was given an introduction and demonstration for each ADI display. The introduction was provided to subjects just prior to their use of the ADI type for the first time, with no mention of the other ADI display. The details of this process are given in the ADI Training Procedure of Appendix E.

5.6 Experimental Measurements

The experimenter was provided with a set of three-digit codes. The simulator was configured for each specific task automatically by entering a run code number into the simulator interface. The run codes are given in Appendix F.

During each run, the pilot's inputs, the turbulence and upset attitude seed parameter, and the experimenter's keyboard toggles were recorded. This allowed offline reproduction of the completed runs to acquire additional data as necessary at a later time. A number of objective measurements were also computed online during each run. After each session in the simulator, the pilot completed a NASA TLX workload rating and a simple questionnaire (see Section 5.6.2).

5.6.1 Objective Measurements

The objective measurements were displayed to the experimenter at the end of each run, as well as stored in a computer file. Appendix G contains printouts of typical file results representing each piloting task type. For each parameter 4 numbers are given representing, from left to right, the mean, standard deviation, maximum, and minimum.

5.6.1.1 Level Tracking

After the start of a level tracking task, a keyboard toggle was set by the experimenter once the pilot had established control of the aircraft. A second keyboard toggle was set approximately 90 seconds later to indicate the end of the run. The segment between the two toggles was used to carry out the online analysis. The mean, standard deviation, maximum, and minimum were calculated for the state variables of heading and bank angle.

5.6.1.2 Heading Changes

The heading change task always began with the aircraft heading due north, and the first turn was given approximately 30 seconds into the run. The possible sets of turns are given in Appendix H. Following a "Turn now" instruction, the experimenter toggled the keyboard to indicate the start of a turn. When the experimenter judged the turn to be complete, a second keyboard toggle was inputted to indicate the end of a turn. This was repeated for the second and third turn, with each turn occurring approximately 30 seconds following the completion of the previous turn. Approximately 30 seconds after the completion of the third turn, a seventh toggle was inputted to indicate the end of the run.

The middle third of the run segments from toggles one to two, 3 to 4 and 5 to 6 were used to carry out online analysis of the mean, standard deviation, maximum, and minimum of the bank angle during each respective turn. The same measurements for heading angle maintained following each turn were calculated using the middle third of the run segments from toggles two to 3, 4 to 5, and 6 to 7. Also calculated are similar measurements for the secondary task both during and following each turn in all of the segments as specified above.

5.6.1.3 Sudden Attitude Upset

Since the sudden upset occurred at a random time generated by the computer, the toggle to indicate the start of the upset was set automatically when the upset was initiated. The experimenter set a second toggle once he judged the pilot to have successfully recovered from the upset. This run segment was then used for online analysis of roll angle and the pilot's aileron input (in radians). The mean, standard deviation, the maximum, and the minimum for each of the above parameters were calculated.

5.6.1.4 Unusual Attitude Recovery

The toggle to indicate the start of an unusual attitude recovery run was set automatically at the moment the display was unblanked. The experimenter set a second toggle once he judged the pilot to have successfully recovered from the unusual attitude. Similar to the sudden attitude upset runs, the run segment was then used for online analysis of roll angle and the pilot's aileron input (in radians). The mean, standard deviation, the maximum, and the minimum for each of the above parameters were calculated.

5.6.2 Subjective Measurements

The subjective measurements taken in this study consisted of the NASA TLX workload assessment and a short questionnaire. These measurements were made for every subject after each session in the simulator.

5.6.2.1 NASA TLX

The NASA Task Load Input (TLX) workload assessment technique is described in Reference [16]. For this experiment, three additional questions suggested by DCIEM were added to the basic TLX rating scale list and are shown as the last three items in the Rating Scale Definitions table in Appendix I. However, these question were not used in computing the final TLX value, but were recorded separately as a rating in the range 0-100 (low to high).

The TLX data gathering and computing process were streamlined using a computer program written based on Reference [16]. The experimenter's instructions for administering this software version of TLX are given in Appendix J. Figure 5.6.1 shows a computed TLX summary window used by the experimenter. The instructions for test subjects were attached in the Pilot Briefing Document, and are replicated in Appendix G. Sample windows of the GUI as used by the subjects are shown in Figures 5.6.2 and 5.6.3. A summary printout of the TLX results to date was produced at the end of each experiment day for the active pilot. A sample printout is given in Appendix K, with the identifier letter blocks using the standard notation employed throughout this experiment:

- H – Conventional Moving Horizon ADI
- F – Frequency Separated ADI
- N – No Simulator Motion Present
- M – Simulator Motion Present
- A – Audio Secondary Task
- V – Visual Secondary Task

The paired choices of the workload weightings were administered for each particular combination of ADI type, simulator motion condition, and secondary task type for each subject at the end of each block (i.e. HNA, HNV, HMA, HMV, FNA, FNV, FMA or FMV).

5.6.2.2 Questionnaire

After each session, the subjects were given the option to fill out the short questionnaire given in Appendix L. This provided the test subjects an opportunity to record free comments on any aspect of the experiment.

The Psycho-Physiological Response Questionnaire was for use only when a pilot responded in the affirmative to Question 2 on the short questionnaire. However, no pilots in the experiment responded in the affirmative to that question, and therefore the Psycho-Physiological Response Questionnaire was never administered.

5.6.3 Subject Performance Feedback

During the course of the experiment, the pilots were never shown any of their performance measures, nor was any qualitative feedback on their performance given. In the case of the secondary task, the experimenter was permitted to give reminders to the subject should the output be allowed to remain fixed at its maximum or minimum value for an extended period of time. This did not occur very often.

5.7 Experimenter's Material

A number of log sheets and checklists, as shown in Appendix M, were developed to assist the experimenter. The checklist was used to aid in preparation prior to each simulator session. The log sheets were completed during and following each session to keep track of subject progress.

Table 5.2.1

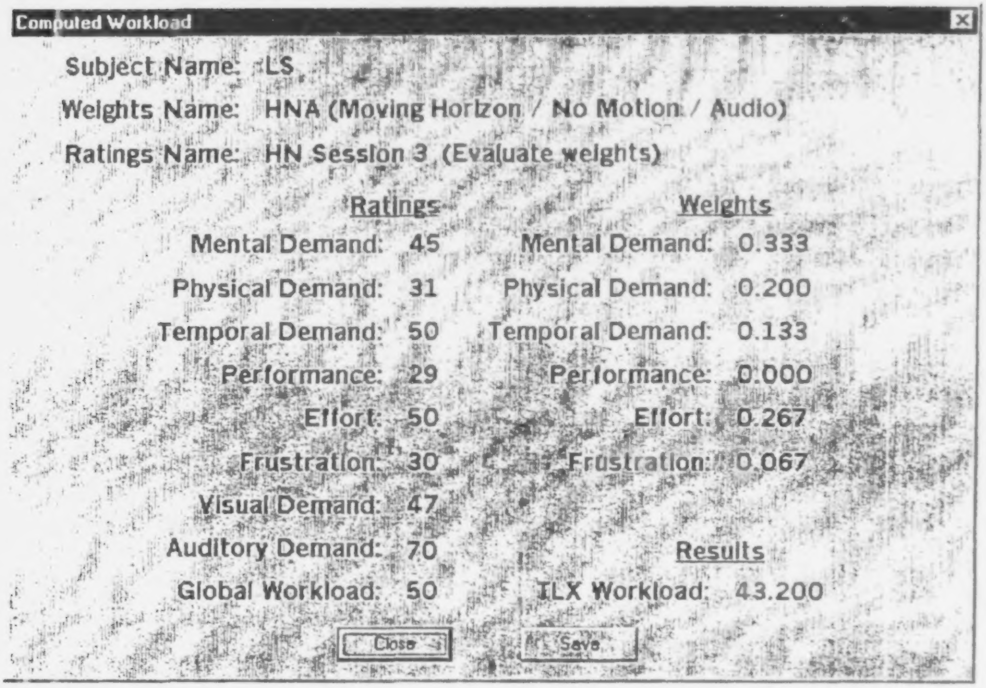
Simulator Experiment Test Matrix

	Group 1	Group 2	Group 3	Group 4
Block 1	HN	HM	FN	FM
Block 2	HM	HN	FM	FN
Block 3	FM	FN	HM	HN
Block 4	FN	FM	HN	HM

H – Conventional Moving Horizon ADI
F – Frequency Separated Display ADI
N – No Motion
M – Motion

Figure 5.6.1

NASA TLX Computed Workload



Subject Name: LS

Weights Name: HNA (Moving Horizon / No Motion / Audio)

Ratings Name: HN Session 3 (Evaluate weights)

Ratings

Mental Demand: 45
Physical Demand: 31
Temporal Demand: 50
Performance: 29
Effort: 50
Frustration: 30
Visual Demand: 47
Auditory Demand: 70
Global Workload: 50

Weights

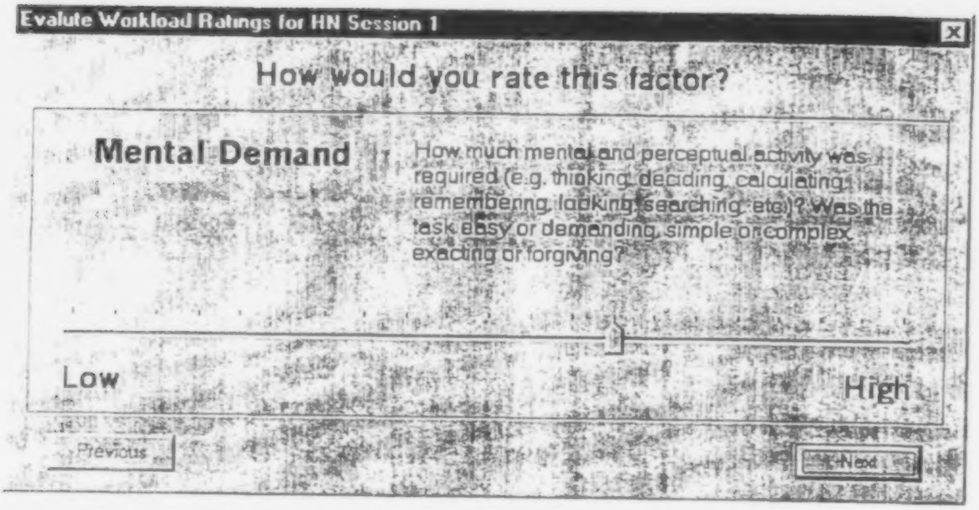
Mental Demand: 0.333
Physical Demand: 0.200
Temporal Demand: 0.133
Performance: 0.000
Effort: 0.267
Frustration: 0.067

Results

TLX Workload: 43.200

Figure 5.6.2

NASA TLX GUI Ratings



Evalute Workload Ratings for HN Session 1

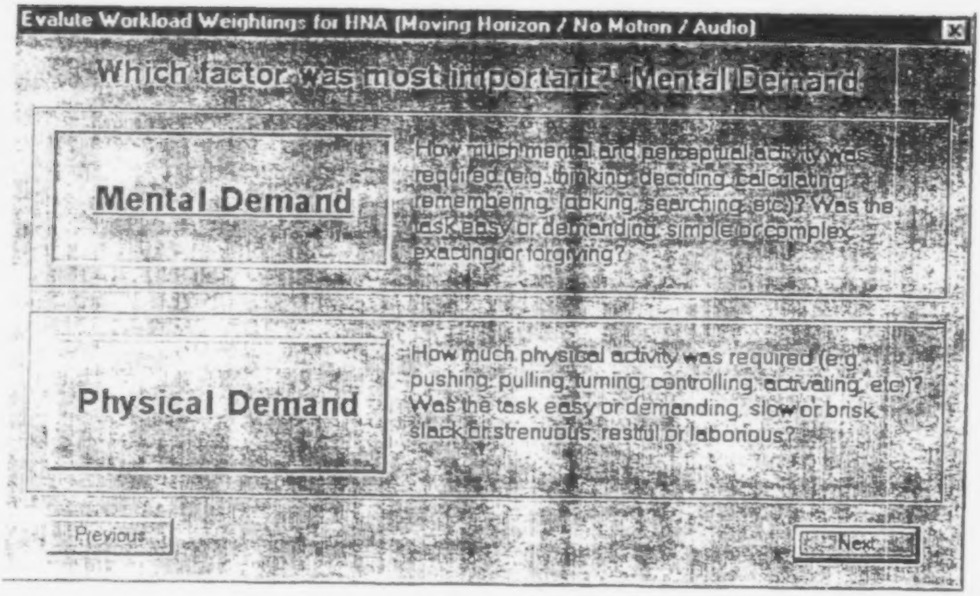
How would you rate this factor?

Mental Demand

How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Figure 5.6.3

NASA TLX GUI Weightings



Evalute Workload Weightings for HNA (Moving Horizon / No Motion / Audio)

Which factor was most important? Mental Demand

Mental Demand

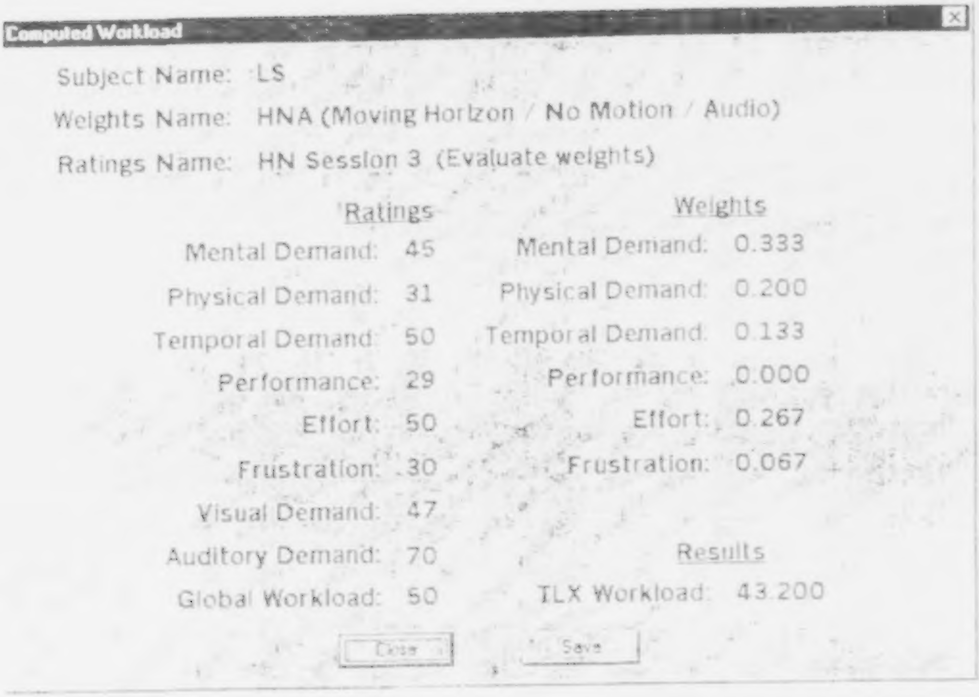
How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical Demand

How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Figure 5.9.2

NASA TLX Computed Workload



Computed Workload

Subject Name: LS

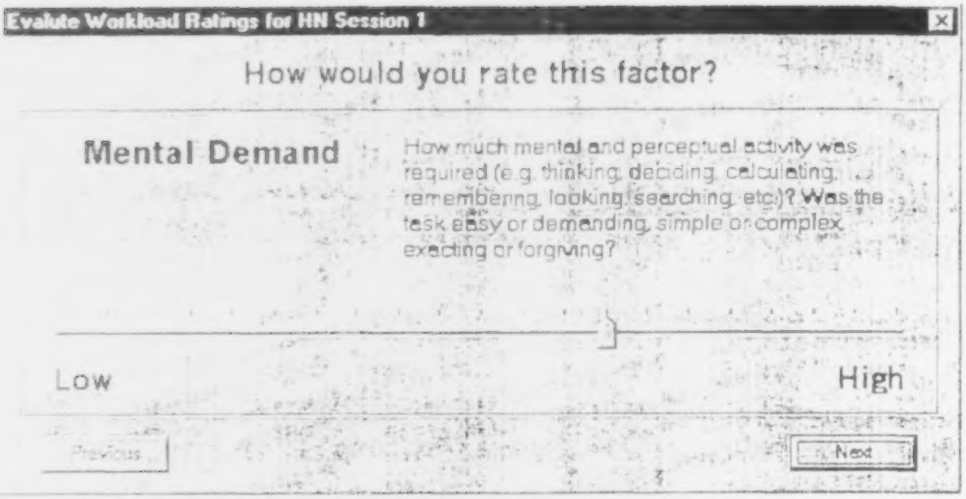
Weights Name: HNA (Moving Horizon / No Motion / Audio)

Ratings Name: HN Session 3 (Evaluate weights)

Ratings		Weights	
Mental Demand:	45	Mental Demand:	0.333
Physical Demand:	31	Physical Demand:	0.200
Temporal Demand:	50	Temporal Demand:	0.133
Performance:	29	Performance:	0.000
Effort:	50	Effort:	0.267
Frustration:	30	Frustration:	0.067
Visual Demand:	47		
Auditory Demand:	70	**Results**	
Global Workload:	50	TLX Workload:	43.200

Figure 5.6.2

NASA TLX GUI Ratings


Evalute Workload Ratings for HN Session 1
Low
High
Previous
Next

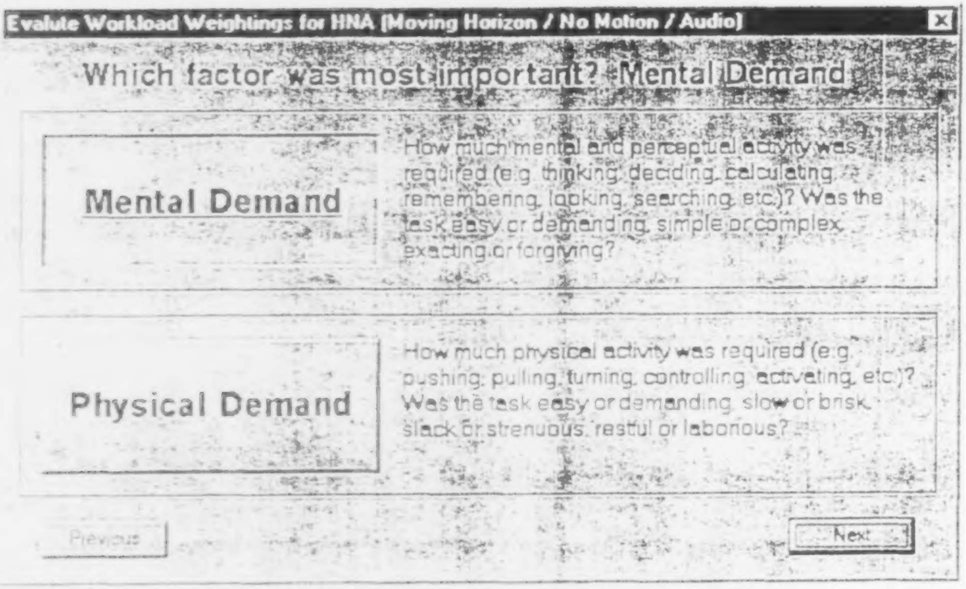
How would you rate this factor?

Mental Demand

How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Figure 5.6.3

NASA TLX GUI Weightings


Evalute Workload Weightings for HNA (Moving Horizon / No Motion / Audio)
Previous
Next

Which factor was most important? Mental Demand

Mental Demand

How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical Demand

How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

6 Analysis of Experimental Data

As stated in Chapter 3, this experiment broadly consisted of two types of runs: continuous events (level tracking and commanded turns), and discrete events (sudden upsets and unusual attitude recoveries). Data collected were analyzed differently based on this classification, with the former primarily used to evaluate pilot performance in routine flight, while the latter was used to detect control reversals.

Also considered is the pilot feedback through NASA TLX ratings and the questionnaires.

6.1 Continuous Events

Analysis of continuous events was based on the average and standard deviations of various parameters. The parameters considered were as follows:

Level Tracking

- Bank
- Heading
- Secondary task performance

Commanded Turns

- Bank during each turn
- Heading after each turn
- Secondary task performance during each turn
- Secondary task performance after each turn

Average and standard deviation were calculated based on the toggles input by the experimenter as explained in Section 5.6.1.

The statistical significance of the data collected was analyzed using an Analysis of Variance of the SPSS software package. For evaluation, the last two runs for each given task and condition were used. Means were simply averaged, and standard deviations were added in quadrature. That is

$$SD_{Final} = \sqrt{\frac{SD_1^2 + SD_2^2}{2}}$$

The within subject variables were ADI type, motion on/off, and secondary task type, resulting in 8 conditions. The between subject variable was the ADI type used first. Therefore, the following main effects and interactions were analyzed:

- ADI
- ADI x HFIRST
- MOTION
- MOTION x HFIRST
- SECTASK
- SECTASK x HFIRST
- ADI x MOTION
- ADI x MOTION x HFIRST
- ADI x SECTASK
- ADI x SECTASK x HFIRST
- MOTION x SECTASK
- MOTION x SECTASK x HFIRST
- ADI x MOTION x SECTASK
- ADI x MOTION x SECTASK x HFIRST

Here, ADI denotes ADI type, HFIRST denotes whether the conventional moving horizon ADI was introduced first, MOTION denotes motion on/off, and SECTASK denotes secondary task type.

SPSS found that for the continuous tasks the majority of factors were not significant when using a criterion of $P < 0.1$. $P < 0.1$ is a value that has been found to be appropriate for human factors research in the UTIAS Flight Research Laboratory. There were several significant terms for ADI, MOTION, and SECTASK. A relatively large number of significant terms were found for the interaction term ADI x HFIRST. As well, there were a number of significant higher order terms scattered among the different tasks. The complete charts of Analysis of Variance significance values are given in Appendix N, with significant terms at $P < 0.1$ highlighted. A chart of Mean Square Errors can also be found in Appendix N.

Note that in Appendix N and all other figures in this chapter, Bank refers to the bank error during banked turns, Heading refers to the heading error after banked turns, Level refers to level tracking tasks, and Sec refers to secondary task performance. Also note that secondary task mean and SD have been normalized to give unity for full scale on the display.

6.1.1 ADI x HFIRST Interaction Effects

Of all the interaction terms ADI x HFIRST was significant at $P < 0.1$ for the most number of cases. Out of the 38 cases, 19 were significant with respect to ADI x HFIRST at $P < 0.1$. These are illustrated in Figures 6.1.1 to 6.1.5. Recall that each subject always completed one ADI type before switching to the next. Note for example Figure 6.1.1 (ADI Type and First ADI Exposure Interaction in 20 Degree Turns). The group with the moving horizon ADI first is shown by the dark line and the averaged results of all their runs using the moving horizon ADI (all of which were completed prior to switching to the frequency separated ADI) are shown by the left hand symbol. The group with the frequency separated ADI first is shown by the light line and the averaged results of all their runs using the frequency separated ADI (all of which were completed prior to switching to the moving horizon ADI) are shown by the right hand symbol. As can be seen in the figures, the majority show crossed lines, indicating an improvement in performance when transiting from the first ADI to the second ADI type, regardless of which type was introduced first. This is indicative of learning effects.

6.1.2 ADI Effects

Figures 6.1.6 to 6.1.10 show the comparison between ADI types for means and standard deviations averaged over all subjects, both motion types and both secondary task types, of all the measured parameters. Parameters for which the analysis of variance showed significance at the $P < 0.1$ level for ADI were 20 degree bank SD, 40 degree heading secondary task mean, 50 degree bank mean, level tracking bank angle mean,

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level tracking heading mean, and level tracking heading SD. That is, 6 out of 38 cases were significant. The significant ADI parameters are summarized numerically in Table 6.1.1.

With respect to flight performance, only two out of 16 measured parameters were significant at $P < 0.1$ for commanded turns. It is likely that ADI type had little effect on commanded turns performance. In contrast, 3 out of 4 measured parameters for level tracking performance were significant at $P < 0.1$. Furthermore, all 3 parameters (bank mean, heading mean, and heading SD) showed improvements while using the frequency separated ADI. Mean and SD are both performance measures, and both parameters were lower in magnitude for level tracking heading with the frequency separated ADI. Therefore, ADI type does show a significant effect on level tracking performance, with the frequency separated ADI yielding better performance.

6.1.3 Simulator Motion Effects

Figures 6.1.11 to 6.1.15 show the comparison between motion and no motion for means and standard deviations averaged over all subjects, both ADI types and both secondary task types, of all the measured parameters. Parameters for which the analysis of variance showed significance at $P < 0.1$ for MOTION were 30 degree bank SD, 40 degree bank mean and SD, 40 degree bank secondary task SD, 50 degree heading SD, and 50 degree heading secondary task mean. With the exception of the 40 degree bank mean, all significant parameters showed improved performance with motion present. The significant MOTION parameters are summarized numerically in Table 6.1.2.

None of the flight performance parameters were significant for Motion at $P < 0.1$ for level tracking, indicating that motion had no effect on level tracking performance. Only 4 out of 16 parameters were significant at $P < 0.1$ for commanded turns flight performance. Of the 4, 3 showed improved performance with motion present. It would appear that there are no major motion effects on commanded turns flight performance.

6.2 Discrete Events

The primary goal in analyzing discrete events was to identify pilot control reversals, and therefore simple analysis of aircraft parameters as in continuous events was not adequate. In order to identify control reversals, the criteria for a control reversal first had to be established.

6.2.1 Defining Condition for Control Reversal

As stated in Section 4.5, the sudden upset signal was implemented directly as an aileron input. Therefore, a pilot aileron input in the opposite direction and of the same magnitude and duration would exactly cancel out the sudden upset. As such, control reversals can be identified by observation of pilot aileron input. That is, a pilot aileron input in the same direction as the sudden upset signal after a certain effective time delay constitutes a control reversal.

For the unusual attitude recoveries, the initial bank was achieved by a predetermined aileron input. Therefore, the same condition for control reversals applies. Using this definition of control reversal, a number of runs were isolated for further study. Figure 6.2.1 shows the time history of a typical sudden attitude upset run involving a control reversal. In this example, the pilot's initial response at t = 85.5 s was in the same direction as the sudden upset signal. The pilot was then apparently confused, reversing the aileron inputs before making a second reversed aileron input at t = 86.6 s that caused the aircraft to roll to a bank of almost 90 degrees before successfully recovering. Figure 6.2.2 shows the time history for a typical unusual attitude recovery run involving a control reversal. It is clearly seen in this example that the pilot's aileron input was in the wrong direction and caused the aircraft to roll from the initial bank of 67 degrees to approximately 85 degrees before recovering.

6.2.2 Determining Effective Time Delay

Determination of pilot effective time delay was important so as to accurately identify which inputs were reactions to the sudden upset, as opposed to the background turbulence. Pilot effective time delay was also used in the unusual attitude recoveries to determine the starting point for analysis following the unblank.

Since the turbulence inputs were introduced directly into the aileron signal as was the sudden upset, pilot effective time delay can be determined by analysis of the aileron inputs. By determining the correlation between the turbulence and corresponding pilot aileron input in the opposite direction, the pilot effective time delay can be determined.

Figure 6.2.3 shows a correlation plot between the turbulence signal and pilot aileron input. This plot is based on all the data collected in the sudden upset runs for all pilots prior to the actual sudden upset. As can be seen in the plot, the maximum correlation (negative in this case since the turbulence and pilot aileron input are of opposite signs) occurs at approximately one second. Therefore, the pilots' effective time delay can be expected to be in the region of one second after each sudden upset or unblank.

6.2.3 Graphical Representation of Pilot Aileron Input

One method that was used to survey the results was to plot 3-D graphs representing the number of occurrences of a range of pilot aileron inputs versus time. The pilots' aileron inputs were adjusted such that a negative input represents an input in the correct direction (that is, opposite to the upset or unblank signal). In essence, these plots present a map of pilot stick inputs, where control reversals would be observed as positive aileron inputs.

For sudden upsets, all aileron inputs were taken relative to the aileron position at the moment that the sudden upset occurs. Figures 6.2.4 to 6.2.7 are the 3-D plots for the sudden upset recoveries, with separate plots given for each ADI display type. Figures 6.2.4 and 6.2.5 show the entire aileron input range from time zero to 2.75 seconds. See for example Figure 6.2.4. The accumulated aileron inputs at a specified aileron angle (given at integral values only) represent the number of occurrences of aileron values in the range ±0.5 degrees about the integer, in a specified time interval of ±0.125 seconds about the indicated time. These aileron values were accumulated for all runs performed by all subjects, over both motion conditions, and both secondary tasks. Thus, in this example the peak at aileron angle zero and time zero indicates 220 occurrences. The curved "hill" representing the majority of control levels is clearly observable.

Figures 6.2.6 and 6.2.7 are the same plots zoomed in on the positive aileron input area, at time 0.5 seconds to 2.0 seconds and aileron levels 1° to 10°. This area represents where a pilot input would be indicative of a control reversal. A number of control reversals using both displays are evident, shown by the non-zero number of aileron inputs in this area. However, it is not clear from these plots whether more control reversals were performed using either ADI display.

Similar 3-D plots were made using the unusual attitude recovery data, and are shown in Figures 6.2.8 to 6.2.11. Once again, the characteristic curved "hill" representing the majority of control levels is apparent. However, in this case, comparison between Figure 6.2.10 and 6.2.11 shows that the number of control reversals while using the frequency separated display ADI is clearly lower.

An alternate graphical representation of the same data uses contour plots. For sudden upsets, Figures 6.2.12 and 6.2.13 are the contour plots corresponding to Figures 6.2.4 and 6.2.5. For the unusual attitude recoveries, Figures 6.2.14 and 6.2.15 are the contour plots corresponding to Figures 6.2.8 and 6.2.9. By comparison of the plots for the unusual attitude recoveries, and to some extent the sudden upsets, it can be seen that the control inputs for the frequency separated display ADI adhere to a more narrow range. Furthermore, a greater number of positive aileron inputs are observed using the conventional moving horizon ADI display at approximately 2.5 seconds. This is indicative of pilots correcting for overshoots in their original aileron inputs.

6.2.4 Control Reversal Statistics

While the graphical representations provides a qualitative comparison, an actual count of control reversals while using each ADI display type is needed for a more concrete quantitative analysis. For this purpose, two control reversal criteria were investigated, defined as either: (1) a positive aileron input of one degree or greater, or (2) a positive aileron input of two degrees or greater, during the time period from 0.5 seconds to 1.5 seconds. Table 6.2.1 summarizes the control reversal statistics for all the runs carried out in the experiment.

It was of interest to view the distribution of control reversals among the test subjects. However, it should be noted that 4 of the 24 subjects conducted twice as many runs. Therefore, it is not surprising that they had a greater than average number of control reversals. These 4 subjects are highlighted in Table 6.2.1.

Figure 6.2.16 shows the distribution of control reversals for sudden attitude upsets. It can be seen in the figure that for the two degree criterion, most people had one or zero reversals and the number of people decreased as the number of reversals increased. However, for the one degree criterion there was a relatively even distribution of people across the range of number of reversals, with the most people committing two to 5 reversals. This shows that while most people made a number of small reversals, the occurrences of larger control reversals of two degrees or greater aileron input were comparatively rare.

Figure 6.2.17 shows the distribution of control reversals for unusual attitude recoveries. With the two degree criterion, all but 3 subjects committed two or fewer reversals. Similar to the sudden attitude upsets distribution, for the one degree criterion there was a wider distribution of people across the range of number of reversals. This shows once again that in most cases, large control reversals do not occur, but small reversals of less than two degrees aileron input are much more common.

For sudden attitude upsets, the best subject had zero reversals and the worst two subjects had 11 reversals under the one-degree criterion. The average was 4.9 reversals, and the SD 3.2. Under the two-degree criterion, the best subjects had zero reversals and the worst subject had 8. The average was 2.3 reversals, and the SD 2.2.

For the unusual attitude recoveries, the best subjects had zero reversals and the worst subject had 6 reversals under the one-degree criterion. The average was 2.8 reversals, and the SD 1.7. Under the two-degree criterion, the best subjects had zero reversals and the worst subject had 5. The average was 1.3 reversals, and the SD 1.3.

By dividing the number of control reversals by the number of runs performed, a control reversal percentage could be calculated that can be used to compare the performance of each subject regardless of the number of runs they completed. A control reversal percentage was calculated for each simulator configuration (that is, HN, HM, FN, or FM for unusual attitude recoveries, and HNA, HNV, HMA, HMV, FNA, FNV, FMA, and FMV for sudden attitude upsets) for each subject. The control reversal percentages are shown in Tables 6.2.2 to 6.2.5. The SPSS Analysis of Variance was used to analyze the significance of the interactions of the within and among subject variables (i.e. ADI type, simulator motion on/off, secondary task type, and first ADI type used) of the control reversal percentages. The complete charts of Analysis of Variance significance values are given in Appendix N, with significant terms at $P < 0.1$ highlighted. Charts of Mean Square Errors are also contained in Appendix N. As shown in Appendix N, there were no significant ADI x Motion cross effects. The ADI x Motion data can be observed in Table 6.2.6.

For the sudden attitude upsets, a total of 117 control reversals were recorded using the one-degree criterion. Of those, 59% occurred while using the conventional moving horizon ADI. This was the only control reversal case for which the analysis of variance showed significance at the $P < 0.1$ level for ADI. The number of control reversals was reduced to a total of 55 using the two-degree criterion, with the conventional moving horizon ADI accounting for 53%. Thus, a greater number of reversals occurred while using the conventional display for both criteria.

For the unusual attitude recoveries, a total of 67 control reversals were recorded using the one-degree criterion. Of those, 48% occurred while using the conventional moving horizon ADI. Thirty control reversals were recorded using the two-degree criterion, with the conventional moving horizon ADI accounting for 59%. Thus for the unusual attitude recoveries there were a greater number of control reversals using the frequency separated ADI for the one-degree criterion. However, the moving horizon ADI accounting for more control reversals when the two-degree criterion was used.

Also considered were the comparisons between simulator motion and no motion, and the two different types of secondary tasks. The analysis of variance showed significance at the $P < 0.1$ level for Motion in all cases except for unusual attitude recoveries using the one degree criterion. It was found that a larger number of control reversals occurred when motion was present (61% with motion for the one degree criterion, 68% with motion for the two degree criterion) during the sudden attitude upsets. However, the opposite was true for the unusual attitude recoveries (37% with motion for the two degree criterion). See Table 6.2.1 for the complete set of data. More control reversals occurred when using the audio task and the one-degree criterion, with the opposite being true when using the two-degree criterion. However, secondary task type was not shown to be significant at the $P < 0.1$ level in any cases.

The ADI type did not appear to have significant effect on the number of control reversals during unusual attitude recoveries. However, ADI was shown to be significant for one degree criterion in sudden attitude upsets, and the frequency separated display yielded less control reversals in that case. Motion was shown to be significant at $P < 0.1$ in 3 out of 4 cases, suggesting that simulator motion has an effect on performance in discrete events. Unfortunately, it is not clear why motion seemed to help reduce the number of control reversals in unusual attitude recoveries, but impede pilot performance in sudden attitude upsets. Finally, secondary task type did not appear to have significant effect during sudden attitude upsets. This is the desired result as it shows that proper time constants were chosen in balancing the difficulty while using either secondary task.

After studying the above results, the control reversals were further investigated by increasing the control reversal criterion to higher levels of aileron deflection. Plots were made to compare the number of control reversals committed while using the two ADI types in one degree steps of maximum aileron deflection, ranging from 1 to 10 degrees. That is, a total of 10 control reversal criteria were used, each similar to the one and two degree criteria used above but with correspondingly higher aileron deflection levels. Figure 6.2.18 shows the plot for sudden upsets and Figure 6.2.19 shows the plot for unusual attitude recoveries. In these plots, each point represents the total number of control reversals committed by all subjects in which the maximum aileron deflection was at or above the point. It is apparent in Figure 6.2.19 that for unusual attitude recoveries the number of reversals at the 1 degree criteria level is similar for both ADI types, however, the frequency separated display shows increasingly fewer control reversals relative to the moving horizon ADI for higher magnitudes of aileron deflection. There were no control reversals using the frequency separated display ADI with a control reversal criterion of 5 degrees or greater aileron deflection. It can also be seen in Figure 6.2.18 that for the sudden attitude upsets there were fewer control reversals committed while using the frequency separated display ADI across the entire range of aileron deflections.

6.3 Workload Ratings

The UTIAS version of the NASA TLX program produced four final ratings: a TLX workload index, visual workload index, audio workload index, and global workload index. There were a total of eight distinct session types consisting of two ADI types, two motion conditions, and two secondary tasks.

The ratings averaged among all subjects are presented in Figures 6.3.1 to 6.3.4. The numerical values are also summarized in Table 6.3.1. The averaged TLX workload ratings ranged from the lowest value of 34.04 for frequency separated ADI, no motion and visual secondary task, to the highest value of 38.32 for moving horizon ADI, no motion and audio secondary task. The global workload ratings spanned a range from 41.42 for frequency separated ADI, no motion and visual secondary task, to 43.54 for moving horizon ADI, motion and audio secondary task.

The audio and visual workload ratings spanned a much greater range, with the highest audio workload ratings for the sessions using audio secondary task, and the highest visual workload ratings for the sessions using the visual secondary task. Overall, the TLX and global workload ratings were slightly higher for audio secondary task sessions.

Averaged TLX workload ratings for the moving horizon ADI (37.65) were slightly higher than for the frequency separated ADI (36.08), while the averaged global workload were almost identical. However, the visual workload rating was higher for the frequency separated ADI. This is consistent with the comments from a number of subjects who indicated that the moving airplane element of the frequency separated ADI results in increased visual demand.

The sessions with no motion produced slightly higher TLX workload ratings compared with sessions with motion present. However, the opposite was true with the global workload ratings. Both audio and visual workload ratings were higher in sessions with no motion.

The general consensus among the test subjects was that the flight tasks were very manageable in terms of difficulty. Of the test subjects who commented, the majority preferred the frequency separated ADI over the conventional moving horizon display. Most also felt that motion was beneficial to their performance. Secondary task preferences, however, were more varied. Some subjects preferred the audio secondary task since it did not require moving the eyes away from the ADI display. However, others felt that the audio task required more concentration and that it interfered with hearing commands from the experimenter.

6.4 Summary

Both continuous and discrete flight tasks were conducted in this experiment, and the method of analyzing these two types of tasks differed.

For continuous events, analysis of the mean and SD of various parameters was useful. It was found that ADI type had little effect on commanded turns performance. However, ADI type does show significant effect on level tracking performance, with the frequency separated ADI yielding better performance. In terms of simulator motion effects, only 4 out of 16 parameters were significant at $P < 0.1$ for commanded turns flight performance and it would appear that there were no major motion effects for any of the continuous tasks.

The goal of analyzing the discrete events was to identify occurrences of pilot control reversals. Pilot aileron inputs were observed graphically, and the number of control reversals while using the frequency separated display ADI was lower in the unusual attitude recoveries. Furthermore, the control inputs for the frequency separated display ADI were observed to adhere to a more narrow range with less overshoot.

Two criteria for control reversals were defined in order to allow the number of control reversals to be counted for a quantitative analysis. Considering only results for which the analysis of variance showed significance at $P < 0.1$, the ADI type did not appear to have a significant effect on the number of control reversals during unusual attitude recoveries. The apparent contradiction with the graphical observations can be explained by the fact that the frequency separated ADI did not reduce the number of control reversals, but apparently reduced the magnitude of the control reversals. ADI was shown to be significant at $P < 0.1$ for the one degree criterion in sudden attitude upsets, and the frequency separated display yielded less control reversals in that case. Simulator motion had an effect on performance in discrete events, however, its effects were not consistent as it reduced the number of control reversals in unusual attitude recoveries, but impeded pilot performance in sudden attitude upsets.

In the previous University of Illinois simulator studies, improved performance was observed in a commanded heading changes task while using the frequency separated ADI. In this experiment, ADI type was not found to have a significant effect on performance in the commanded heading changes task indicating similar performance using either ADI type.

The improved performance with simulator motion present observed at the University of Illinois were not observed in this experiment. In the present study, the only tasks in which motion affected performance were discrete events, which were not performed in the simulator in any of the past studies.

The flight experiments conducted by the University of Illinois consisted of an attitude tracking task and an unusual attitude task similar to the level tracking task and unusual attitude recovery task of this experiment. In their flight experiments, it was shown that the frequency separated display provided at least equivalent pilot attitude tracking performance as the moving horizon display, while reducing the number of control reversals in the unusual attitude recoveries. This is similar to the findings of this experiment that showed improved performance while using the frequency separated ADI in level tracking, and reduced number of control reversals overall. The results of this experiment most closely resemble those of the past in-flight experiments.

Table 6.1.1

Summary of Significant Parameters in ADI Type

Parameter	***Conventional ADI***	***Frequency Separated ADI***
20 Degree Bank SD deg	1.199	0.924
40 Degree Heading Sec Mean	-1.392×10^{-2}	4.270×10^{-3}
50 Degree Bank Mean deg	0.116	-0.120
Level Tracking Bank Mean deg	0.299	0.100
Level Tracking Heading Mean deg	0.688	0.231
Level Tracking Heading SD deg	1.692	1.214

Table 6.1.2

Summary of Significant Parameters in Motion/No Motion

Parameter	***No Motion***	***Motion***
30 Degree Bank SD deg	1.167	1.014
40 Degree Bank Mean deg	-0.076	0.111
40 Degree Bank SD deg	1.250	1.009
40 Degree Bank Sec SD deg	8.078×10^{-2}	5.427×10^{-2}
50 Degree Heading SD deg	0.506	0.452
50 Degree Heading Sec Mean	-1.575×10^{-2}	-2.381×10^{-4}

Table 6.2.1

Control Reversals for Two Criteria

	Sudden Upsets			Unblanks		
Subject	1 degree	2 degree	Total Runs	1 degree	2 degree	Total Runs
BK	0	0	16	2	0	32
CR	5	3	16	5	3	32
DA	4	1	16	1	1	32
DC	3	2	16	2	0	32
DH	6	3	16	3	2	32
DW	8	7	16	5	0	32
EC	11	8	16	2	1	32
EL	5	0	16	4	2	32
IS	4	3	16	4	2	32
JA	1	0	16	2	0	32
JI	3	1	16	2	0	32
JJ	4	0	16	0	0	32
LS	10	4	32	5	2	64
MM	11	5	32	6	5	64
OH	3	2	16	5	2	32
PB	6	1	16	3	2	32
PZ	3	1	16	0	0	32
RF	0	0	16	3	2	32
SI	4	2	16	3	2	32
TF	2	1	16	4	3	32
TH	8	2	32	2	0	64
TL	2	1	16	2	0	32
TS	8	5	32	1	0	64
YG	6	3	16	1	1	32
Avg	*4.9*	*2.3*		*2.8*	*1.3*	
SD	*3.2*	*2.2*		*1.7*	*1.3*	
1st Quartile	*3.0*	*1.0*		*2.0*	*0.0*	
Median	*4.0*	*2.0*		*2.5*	*1.0*	
3rd Quartile	*6.5*	*3.0*		*4.0*	*2.0*	
H	69	29	224	32	19	448
F	48	26	224	35	11	448
M	71	36	224	30	11	448
N	46	19	224	37	19	448
A	63	25	224			
V	54	30	224			

Letters appearing under "Subject" are test subject initials Highlighted are subjects who completed double length schedules

H – Conventional ADI	F – Frequency Separated Display ADI
M – Motion Present	N – No Motion
A – Audio Secondary Task	V – Visual Secondary Task

Table 6.2.2

Control Reversals Percentages for

One Degree Criterion - Sudden Attitude Upsets

	One Degree Criterion – Sudden Attitude Upsets								
Subject	HNA	HNV	HMA	HMV	FNA	FNV	FMA	FMV	Total
BK	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
CR	50.00%	50.00%	0.00%	0.00%	50.00%	0.00%	0.00%	100.00%	31.25%
DA	50.00%	50.00%	0.00%	0.00%	0.00%	50.00%	50.00%	0.00%	25.00%
DC	50.00%	50.00%	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	18.75%
DH	100.00%	0.00%	50.00%	0.00%	50.00%	50.00%	0.00%	50.00%	37.50%
DW	50.00%	0.00%	50.00%	100.00%	0.00%	0.00%	100.00%	100.00%	50.00%
EC	100.00%	50.00%	100.00%	100.00%	50.00%	50.00%	0.00%	100.00%	68.75%
EL	0.00%	50.00%	0.00%	50.00%	50.00%	50.00%	0.00%	50.00%	31.25%
IS	0.00%	0.00%	100.00%	0.00%	50.00%	0.00%	50.00%	0.00%	25.00%
JA	0.00%	0.00%	0.00%	50.00%	0.00%	0.00%	0.00%	0.00%	6.25%
JI	50.00%	50.00%	0.00%	50.00%	0.00%	0.00%	0.00%	0.00%	18.75%
JJ	50.00%	0.00%	50.00%	100.00%	0.00%	0.00%	0.00%	0.00%	25.00%
LS	0.00%	25.00%	100.00%	75.00%	25.00%	0.00%	0.00%	25.00%	31.25%
MM	25.00%	25.00%	25.00%	25.00%	50.00%	25.00%	25.00%	75.00%	34.38%
OH	0.00%	0.00%	50.00%	0.00%	0.00%	0.00%	50.00%	50.00%	18.75%
PB	50.00%	50.00%	50.00%	50.00%	0.00%	50.00%	0.00%	50.00%	37.50%
PZ	0.00%	0.00%	0.00%	50.00%	0.00%	0.00%	0.00%	100.00%	18.75%
RF	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SI	50.00%	0.00%	0.00%	0.00%	50.00%	0.00%	100.00%	0.00%	25.00%
TF	0.00%	0.00%	50.00%	50.00%	0.00%	0.00%	0.00%	0.00%	12.50%
TH	50.00%	50.00%	0.00%	25.00%	0.00%	0.00%	50.00%	25.00%	25.00%
TL	50.00%	0.00%	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	12.50%
TS	25.00%	0.00%	75.00%	0.00%	25.00%	0.00%	50.00%	25.00%	25.00%
YG	50.00%	0.00%	50.00%	100.00%	50.00%	0.00%	50.00%	0.00%	37.50%

This table shows the percentage of runs in which control reversals were committed.
Letters appearing under "Subject" are test subject initials. Highlighted are subjects who completed double length schedules.
H – Conventional ADI
F – Frequency Separated Display ADI
M – Motion Present
N – No Motion
A – Audio Secondary Task
V – Visual Secondary Task

Table 6.2 3

Control Reversals Percentages for

Two Degree Criterion - Sudden Attitude Upsets

	Two Degree Criterion – Sudden Attitude Upsets								
Subject	HNA	HNV	HMA	HMV	FNA	FNV	FMA	FMV	Total
BK	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
CR	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	18.75%
DA	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.25%
DC	50.00%	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	12.50%
DH	0.00%	0.00%	0.00%	0.00%	50.00%	50.00%	0.00%	50.00%	18.75%
DW	50.00%	0.00%	50.00%	100.00%	0.00%	0.00%	50.00%	100.00%	43.75%
EC	50.00%	50.00%	100.00%	50.00%	0.00%	50.00%	0.00%	100.00%	50.00%
EL	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
IS	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	50.00%	0.00%	18.75%
JA	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
JI	0.00%	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.25%
JJ	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
LS	0.00%	0.00%	50.00%	25.00%	25.00%	0.00%	0.00%	0.00%	12.50%
MM	25.00%	0.00%	0.00%	0.00%	50.00%	0.00%	25.00%	25.00%	15.63%
OH	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	50.00%	50.00%	12.50%
PB	0.00%	0.00%	0.00%	50.00%	0.00%	0.00%	0.00%	0.00%	6.25%
PZ	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	50.00%	6.25%
RF	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SI	0.00%	0.00%	0.00%	0.00%	50.00%	0.00%	50.00%	0.00%	12.50%
TF	0.00%	0.00%	0.00%	50.00%	0.00%	0.00%	0.00%	0.00%	6.25%
TH	25.00%	25.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.25%
TL	0.00%	0.00%	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.25%
TS	0.00%	0.00%	50.00%	0.00%	0.00%	0.00%	50.00%	25.00%	15.63%
YG	0.00%	0.00%	0.00%	100.00%	50.00%	0.00%	0.00%	0.00%	18.75%

This table shows the percentage of runs in which control reversals were committed.

Letters appearing under "Subject" are test subject initials Highlighted are subjects who completed double length schedules.

H – Conventional ADI	F – Frequency Separated Display ADI
M – Motion Present	N – No Motion
A – Audio Secondary Task	V – Visual Secondary Task

Table 6.2.4

Control Reversals Percentages for
One Degree Criterion – Unusual Attitude Recoveries

	One Degree Criterion – Unusual Attitude Recoveries				
Subject	HN	HM	FN	FM	Total
BK	12.50%	12.50%	0.00%	0.00%	6.25%
CR	50.00%	12.50%	0.00%	0.00%	15.63%
DA	12.50%	0.00%	0.00%	0.00%	3.13%
DC	12.50%	0.00%	12.50%	0.00%	6.25%
DH	0.00%	12.50%	12.50%	12.50%	9.38%
DW	0.00%	0.00%	12.50%	50.00%	15.63%
EC	12.50%	0.00%	12.50%	0.00%	6.25%
EL	12.50%	25.00%	12.50%	0.00%	12.50%
IS	12.50%	0.00%	25.00%	12.50%	12.50%
JA	0.00%	0.00%	12.50%	12.50%	6.25%
JI	0.00%	0.00%	12.50%	12.50%	6.25%
JJ	0.00%	0.00%	0.00%	0.00%	0.00%
LS	6.25%	0.00%	6.25%	18.75%	7.81%
MM	12.50%	18.75%	6.25%	0.00%	9.38%
OH	25.00%	0.00%	25.00%	12.50%	15.63%
PB	12.50%	0.00%	0.00%	25.00%	9.38%
PZ	0.00%	0.00%	0.00%	0.00%	0.00%
RF	25.00%	0.00%	0.00%	12.50%	9.38%
SI	12.50%	12.50%	0.00%	12.50%	9.38%
TF	12.50%	25.00%	12.50%	0.00%	12.50%
TH	0.00%	6.25%	6.25%	0.00%	3.13%
TL	0.00%	0.00%	12.50%	12.50%	6.25%
TS	0.00%	0.00%	0.00%	6.25%	1.56%
YG	0.00%	0.00%	12.50%	0.00%	3.13%

This table shows the percentage of runs in which control reversals were committed.
Letters appearing under "Subject" are test subject initials. Highlighted are subjects who completed double length schedules.

H – Conventional ADI
M – Motion Present
A – Audio Secondary Task
F – Frequency Separated Display ADI
N – No Motion
V – Visual Secondary Task

Table 6.2.5

Control Reversals Percentages for

Two Degree Criterion – Unusual Attitude Recoveries

	Two Degree Criterion – Unusual Attitude Recoveries				
Subject	HN	HM	FN	FM	Total
BK	0.00%	0.00%	0.00%	0.00%	0.00%
CR	37.50%	0.00%	0.00%	0.00%	9.38%
DA	12.50%	0.00%	0.00%	0.00%	3.13%
DC	0.00%	0.00%	0.00%	0.00%	0.00%
DH	0.00%	12.50%	12.50%	0.00%	6.25%
DW	0.00%	0.00%	0.00%	0.00%	0.00%
EC	0.00%	0.00%	12.50%	0.00%	3.13%
EL	0.00%	12.50%	12.50%	0.00%	6.25%
IS	0 00%	0.00%	12.50%	12.50%	6.25%
JA	0 00%	0.00%	0 00%	0.00%	0.00%
JI	0.00%	0.00%	0.00%	0.00%	0.00%
JJ	0.00%	0.00%	0.00%	0.00%	0.00%
LS	0.00%	0.00%	6.25%	6.25%	3.13%
MM	6.25%	18.75%	6.25%	0.00%	7.81%
OH	25.00%	0.00%	0.00%	0.00%	6.25%
PB	12.50%	0.00%	0.00%	12.50%	6.25%
PZ	0 00%	0.00%	0.00%	0.00%	0.00%
RF	25.00%	0.00%	0 00%	0.00%	6.25%
SI	12 50%	0.00%	0.00%	12.50%	6.25%
TF	12.50%	25.00%	0.00%	0.00%	9.38%
TH	0.00%	0.00%	0.00%	0.00%	0.00%
TL	0.00%	0.00%	0.00%	0.00%	0.00%
TS	0.00%	0.00%	0.00%	0.00%	0.00%
YG	0.00%	0.00%	12.50%	0.00%	3.13%

This table shows the percentage of runs in which control reversals were committed.

Letters appearing under "Subject" are test subject initials. Highlighted are subjects who completed double length schedules.

H – Conventional ADI
F – Frequency Separated Display ADI
M – Motion Present
N – No Motion
A – Audio Secondary Task
V – Visual Secondary Task

Table 6.2.6

ADI x Motion Interaction Showing the Number of Control Reversals

Unblank 1-Degree Criteria

	ADI Type	
	H	F
No Motion	20	17
Motion	12	18

Unblank 2-Degree Criteria

	ADI Type	
	H	F
No Motion	12	7
Motion	7	4

Sudden Upset 1-Degree Criteria

	ADI Type	
	H	F
No Motion	29	17
Motion	40	31

Sudden Upset 2-Degree Criteria

	ADI Type	
	H	F
No Motion	11	8
Motion	18	18

Table 6.3.1

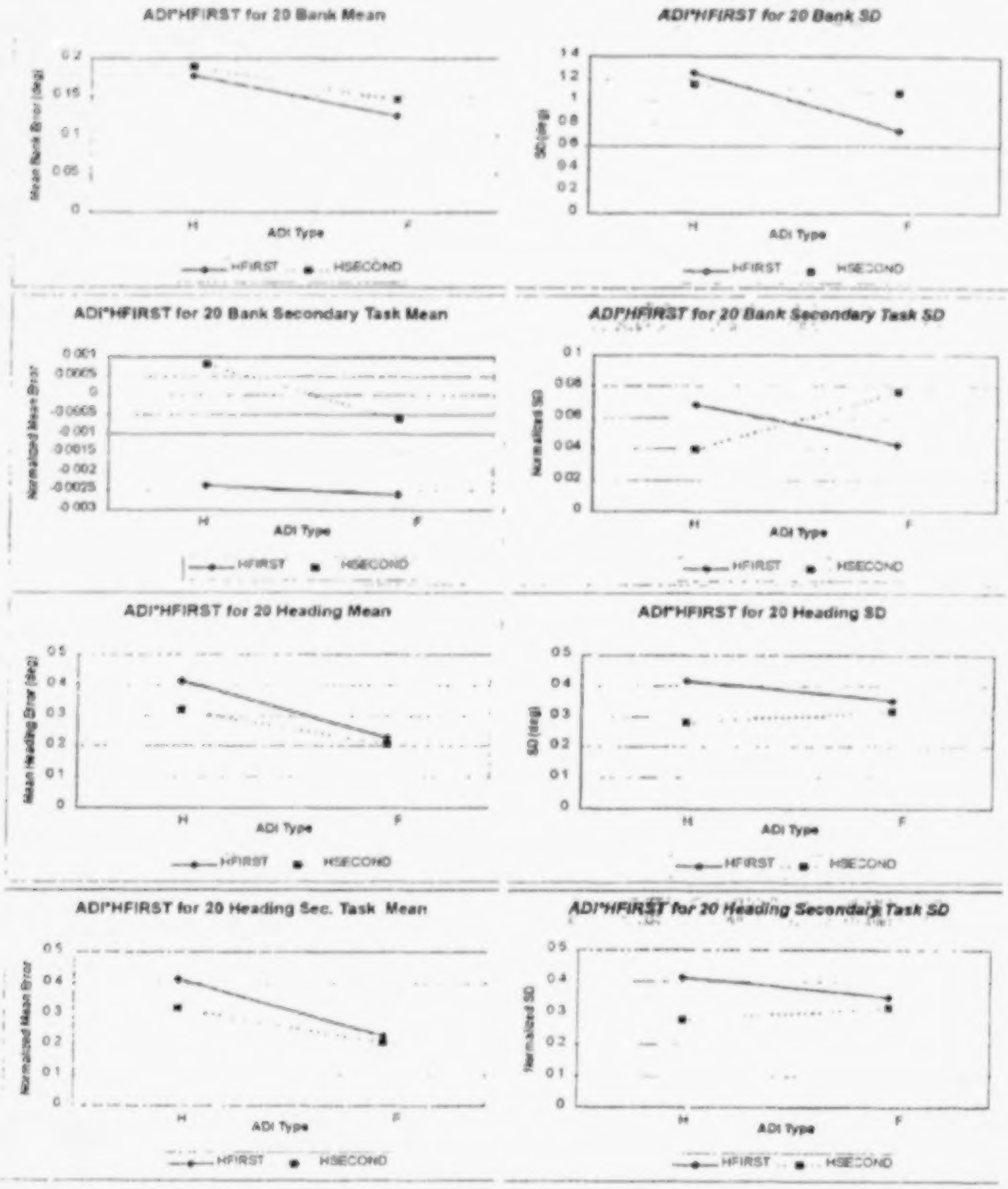
Summary of TLX Results

	TLX Workload	Visual	Audio	Global
HNA	38.32	39.40	55.38	42.54
HNV	38.21	53.60	24.19	43.00
HMA	38.29	33.48	49.75	43.54
HMV	35.79	46.08	23.27	42.48
FNA	37.45	36.46	52.65	43.40
FNV	34.04	51.67	17.48	41.42
FMA	36.41	40.21	52.29	44.85
FMV	36.42	53.19	19.67	41.54
HN	38.26	46.50	39.78	42.77
HM	37.04	39.78	36.51	43.01
FN	35.75	44.06	35.06	42.41
FM	36.42	46.70	35.98	43.20
A	37.62	37.39	52.52	43.58
V	36.11	51.14	21.15	42.11
H	37.65	43.14	38.15	42.89
F	36.08	45.38	35.52	42.80
No Motion	37.00	45.28	37.42	42.59
Motion	36.73	43.24	36.24	43.10

H – Conventional ADI
M – Motion Present
A – Audio Secondary Task
F – Frequency Separated Display ADI
N – No Motion
V – Visual Secondary Task

Figure 6.1.1

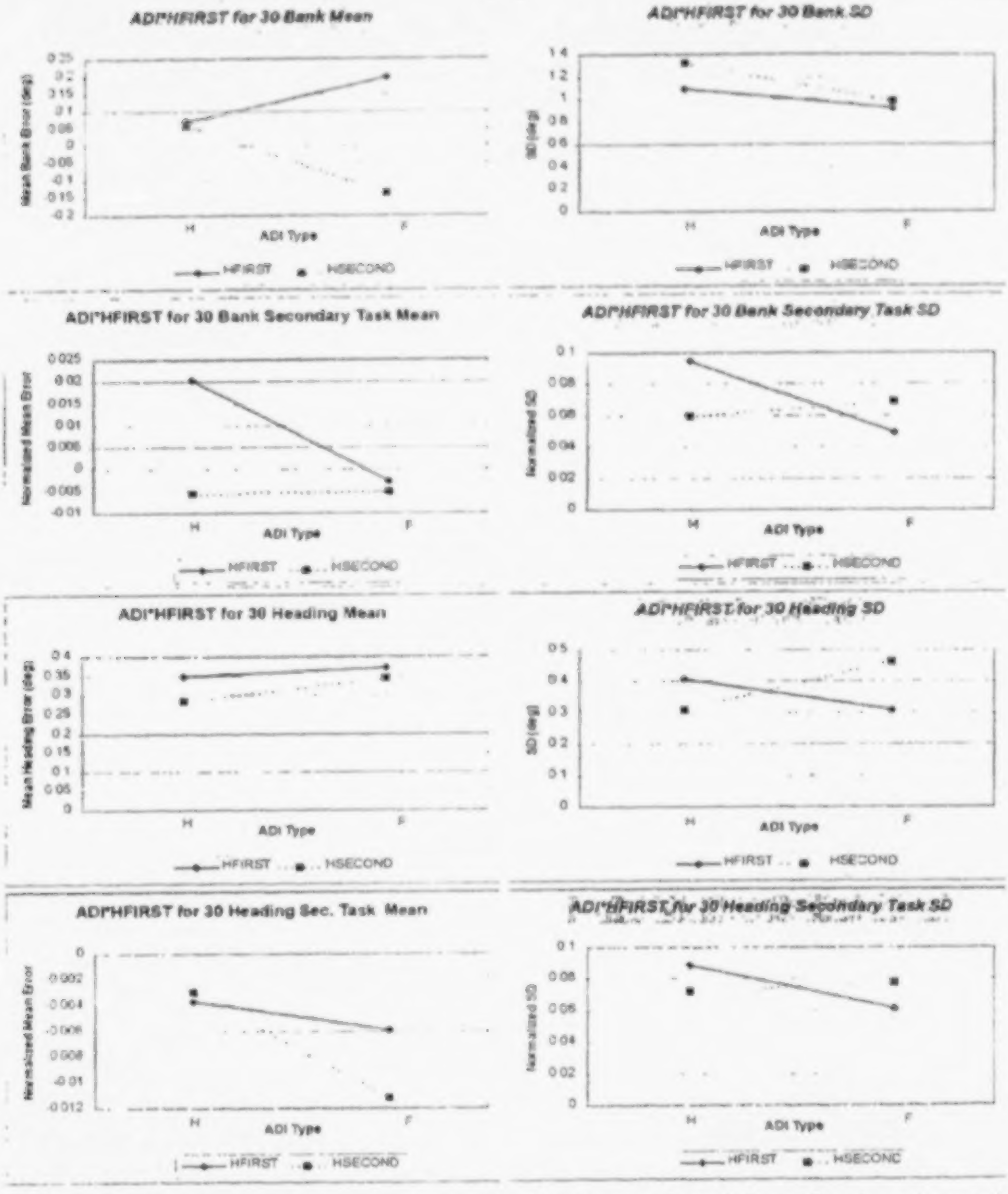
ADI Type and First ADI Exposure Cross Effects in 20 Degrees Turns



Bank refers to the bank error during bank turns. Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized.

Figure 6.1.2

ADI Type and First ADI Exposure Cross Effects in 30 Degrees Turns



ADI*HFIRST for 30 Bank Mean

ADI*HFIRST for 30 Bank SD

ADI*HFIRST for 30 Bank Secondary Task Mean

ADI*HFIRST for 30 Bank Secondary Task SD

ADI*HFIRST for 30 Heading Mean

ADI*HFIRST for 30 Heading SD

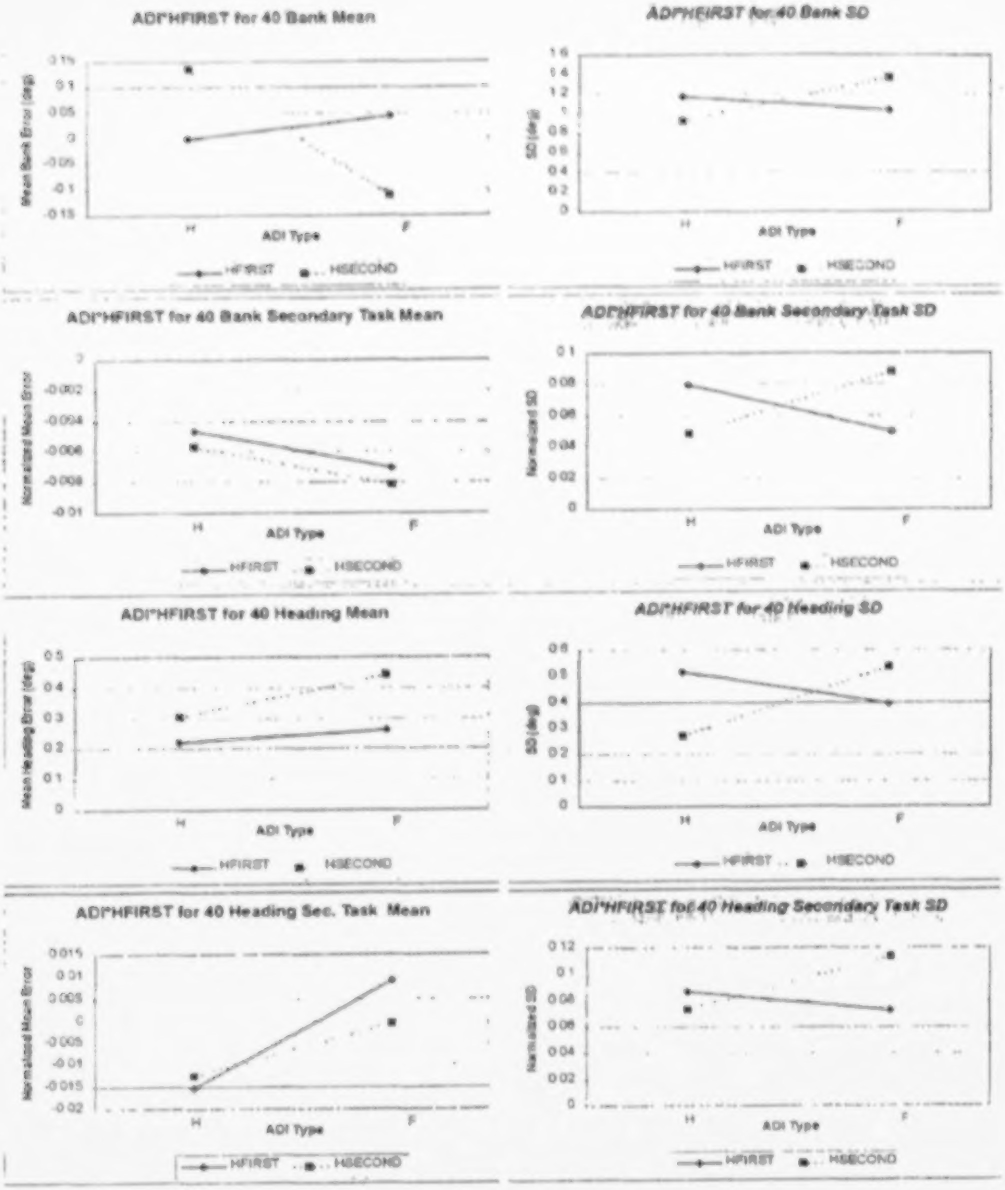
ADI*HFIRST for 30 Heading Sec. Task Mean

ADI*HFIRST for 30 Heading Secondary Task SD

Bank refers to the bank error during bank turns. Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized

Figure 6.1.3

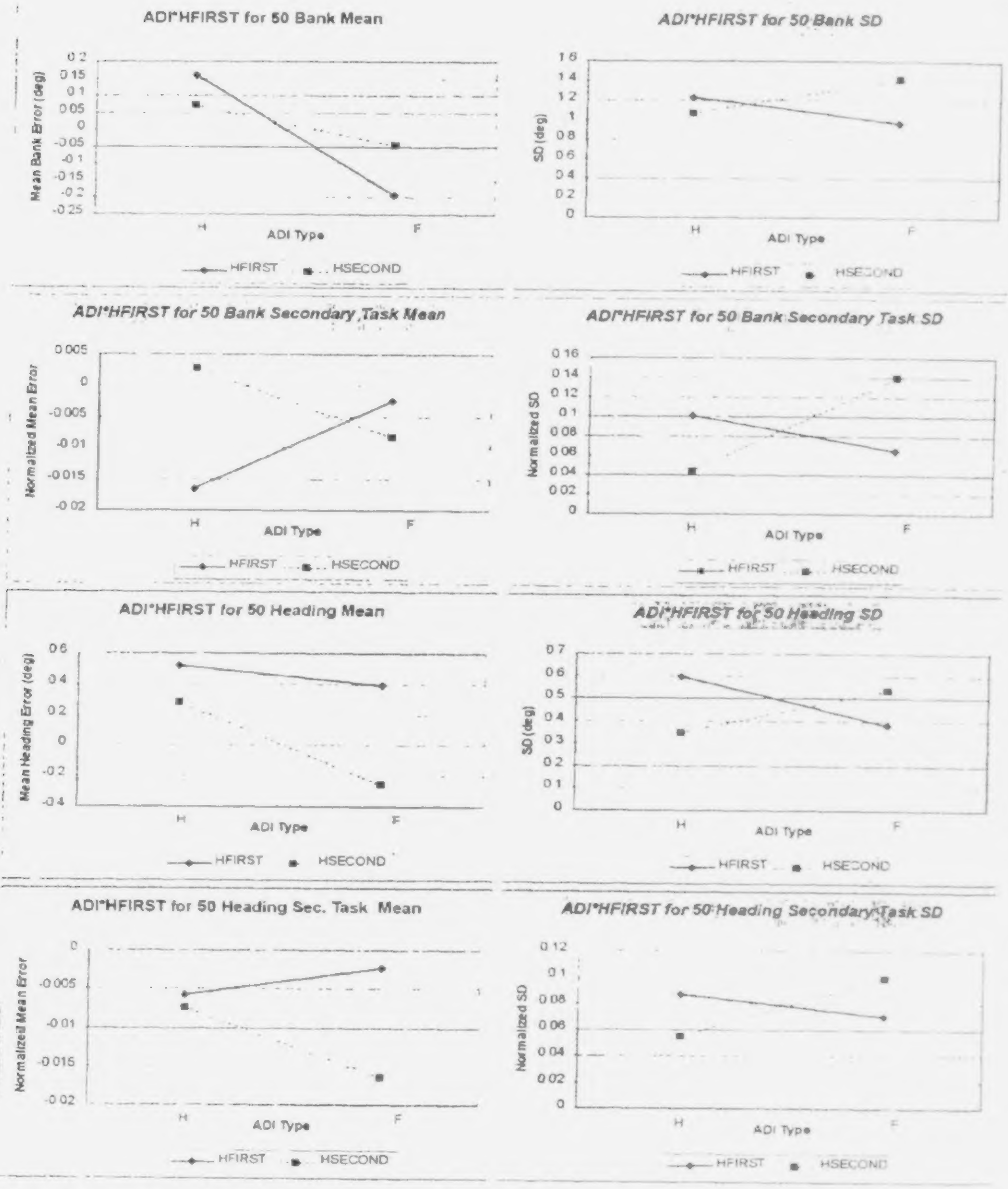
ADI Type and First ADI Exposure Cross Effects in 40 Degrees Turns



Bank refers to the bank error during bank turns, Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized

Figure 6.1.4

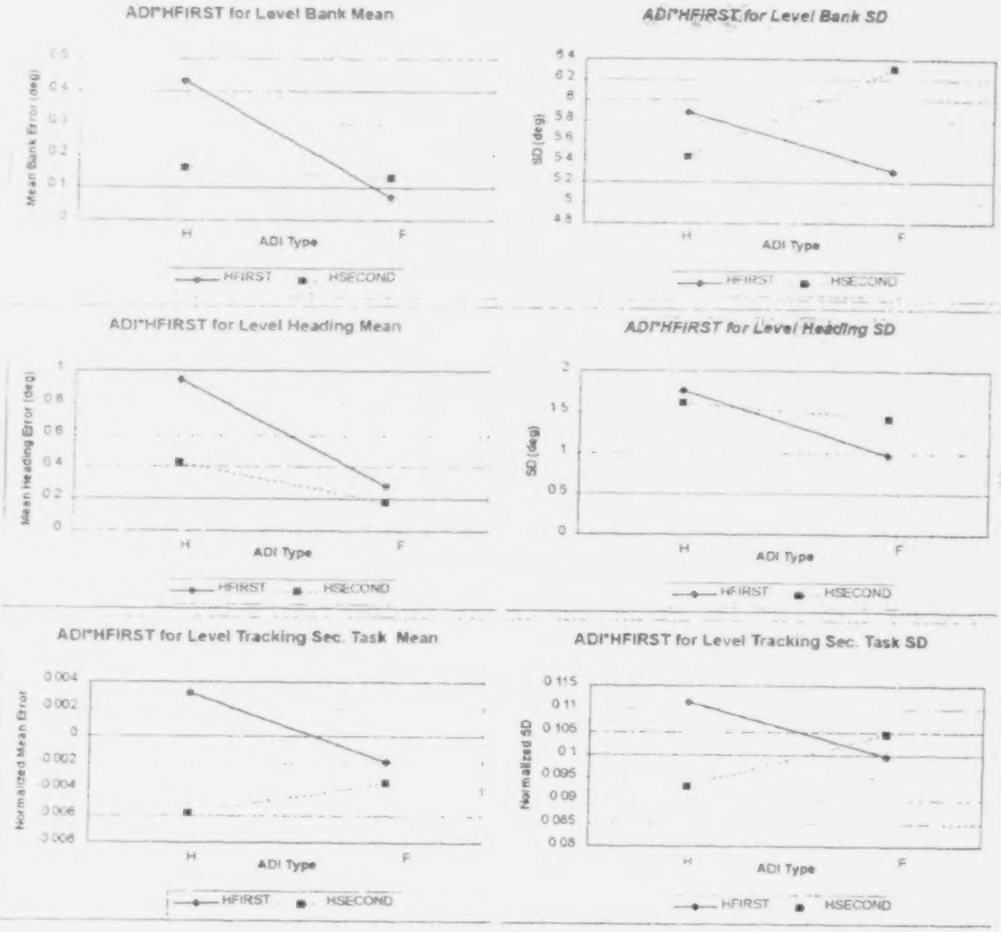
ADI Type and First ADI Exposure Cross Effects in 50 Degrees Turns



Bank refers to the bank error during bank turns. Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized

Figure 6.1 5

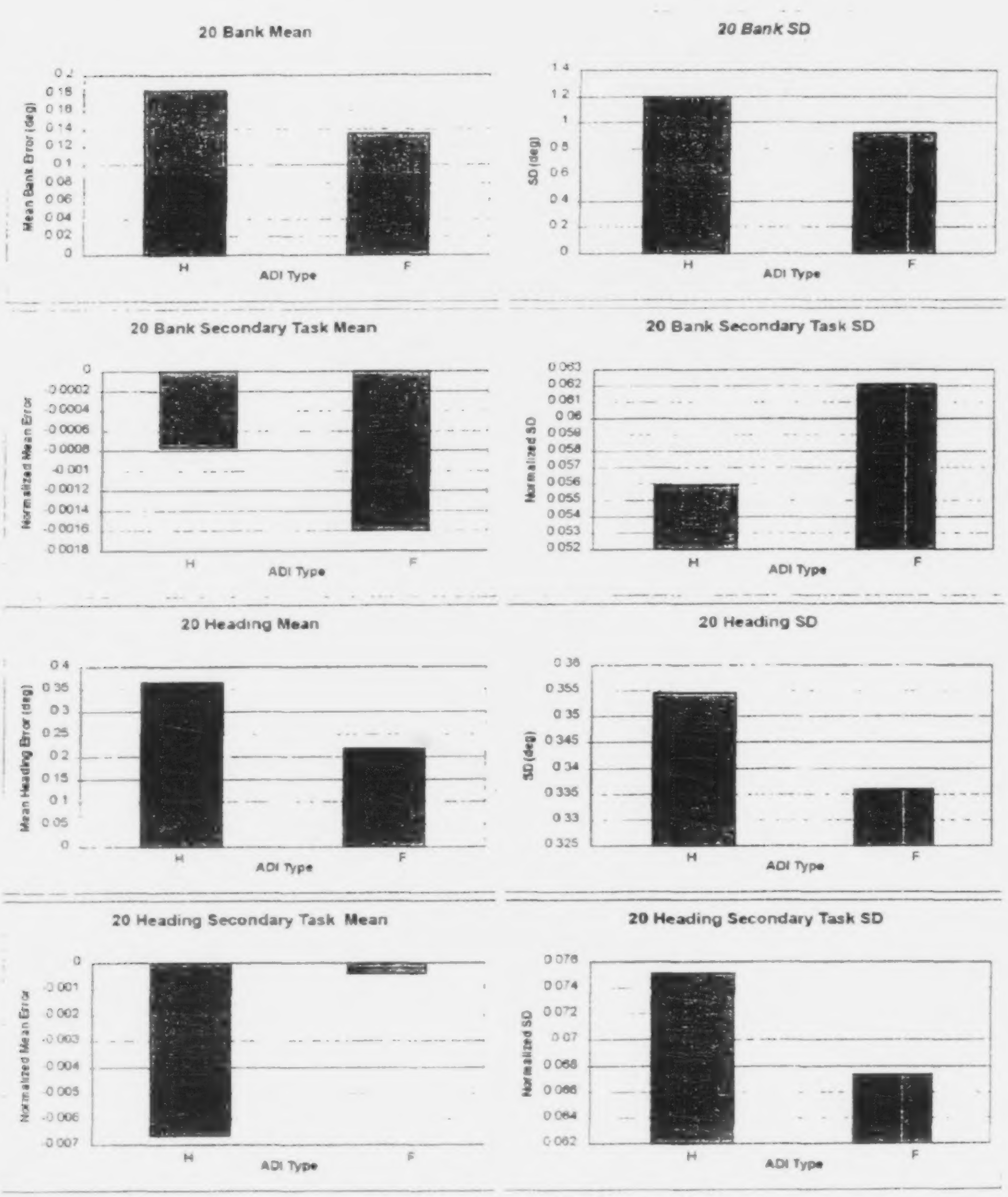
ADI Type and First ADI Exposure Cross Effects in Level Tracking



Secondary task mean and SD have been normalized

Figure 6.1.6

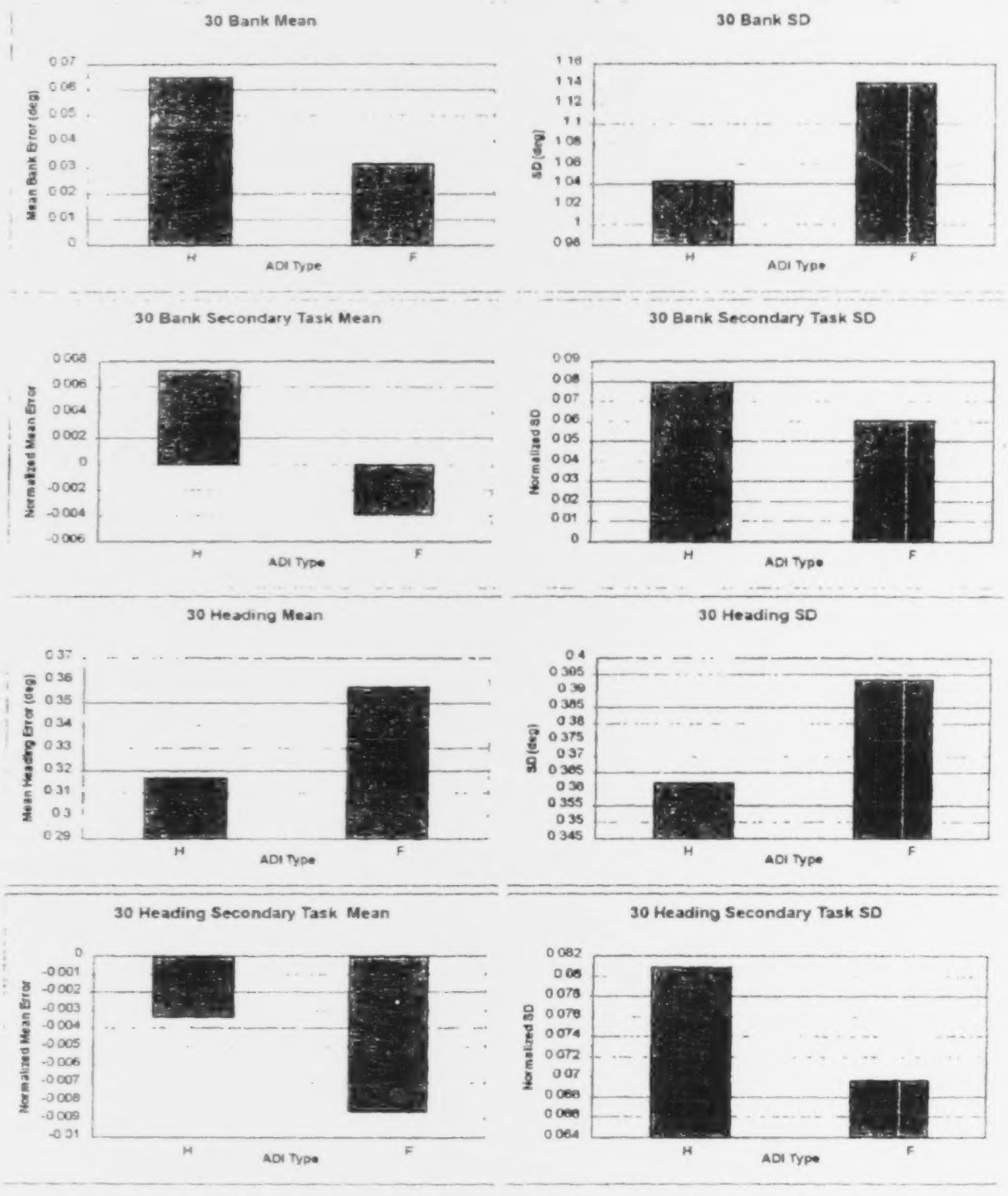
Comparison of Conventional vs. Frequency Separated Display ADI in 20 Degrees Turns



Bank refers to the bank error during bank turns. Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized

Figure 6.1.7

Comparison of Conventional vs. Frequency Separated Display ADI in 30 Degrees Turns



30 Bank Mean

30 Bank SD

30 Bank Secondary Task Mean

30 Bank Secondary Task SD

30 Heading Mean

30 Heading SD

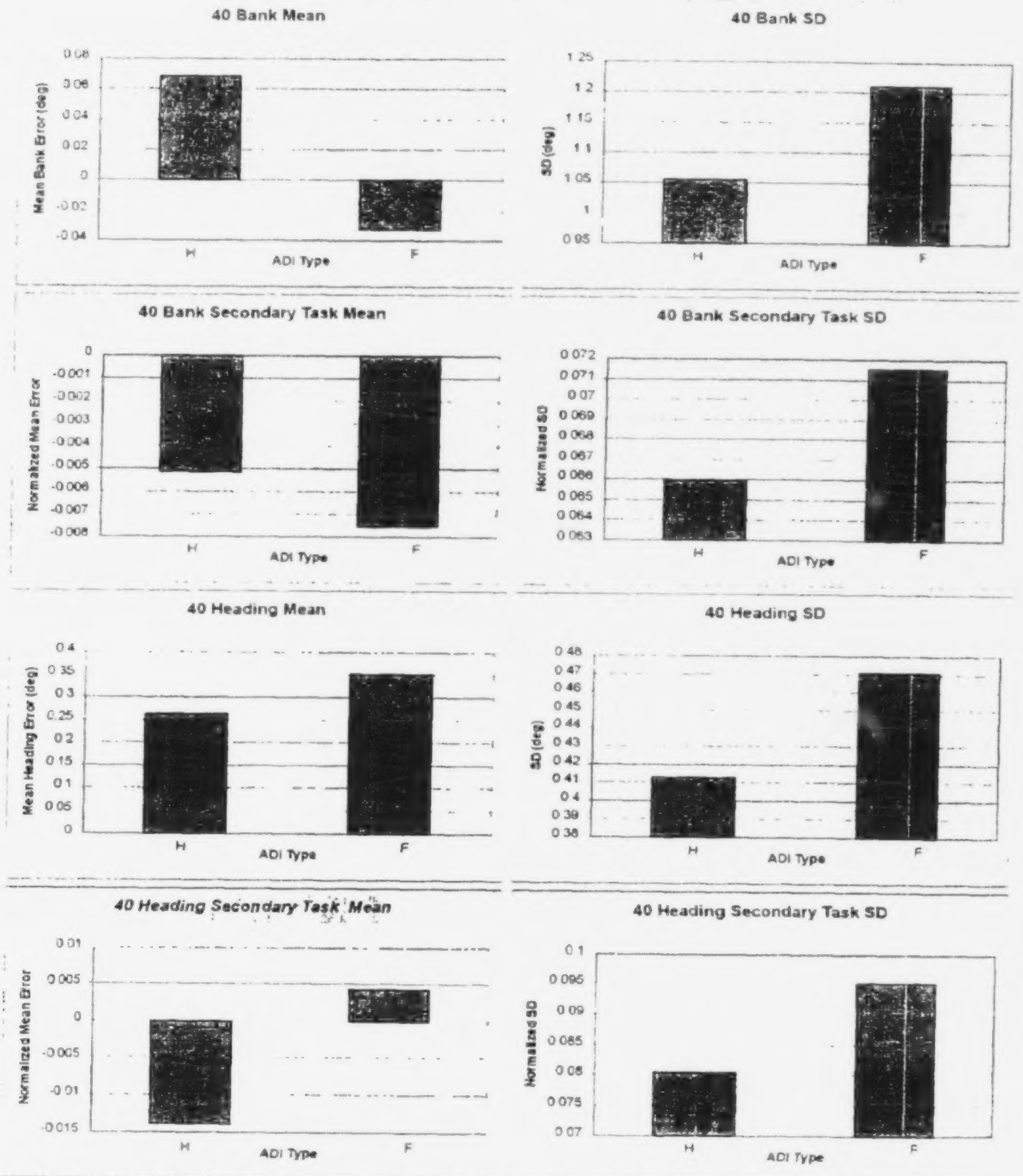
30 Heading Secondary Task Mean

30 Heading Secondary Task SD

Bank refers to the bank error during bank turns. Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized

Figure 6.1.8

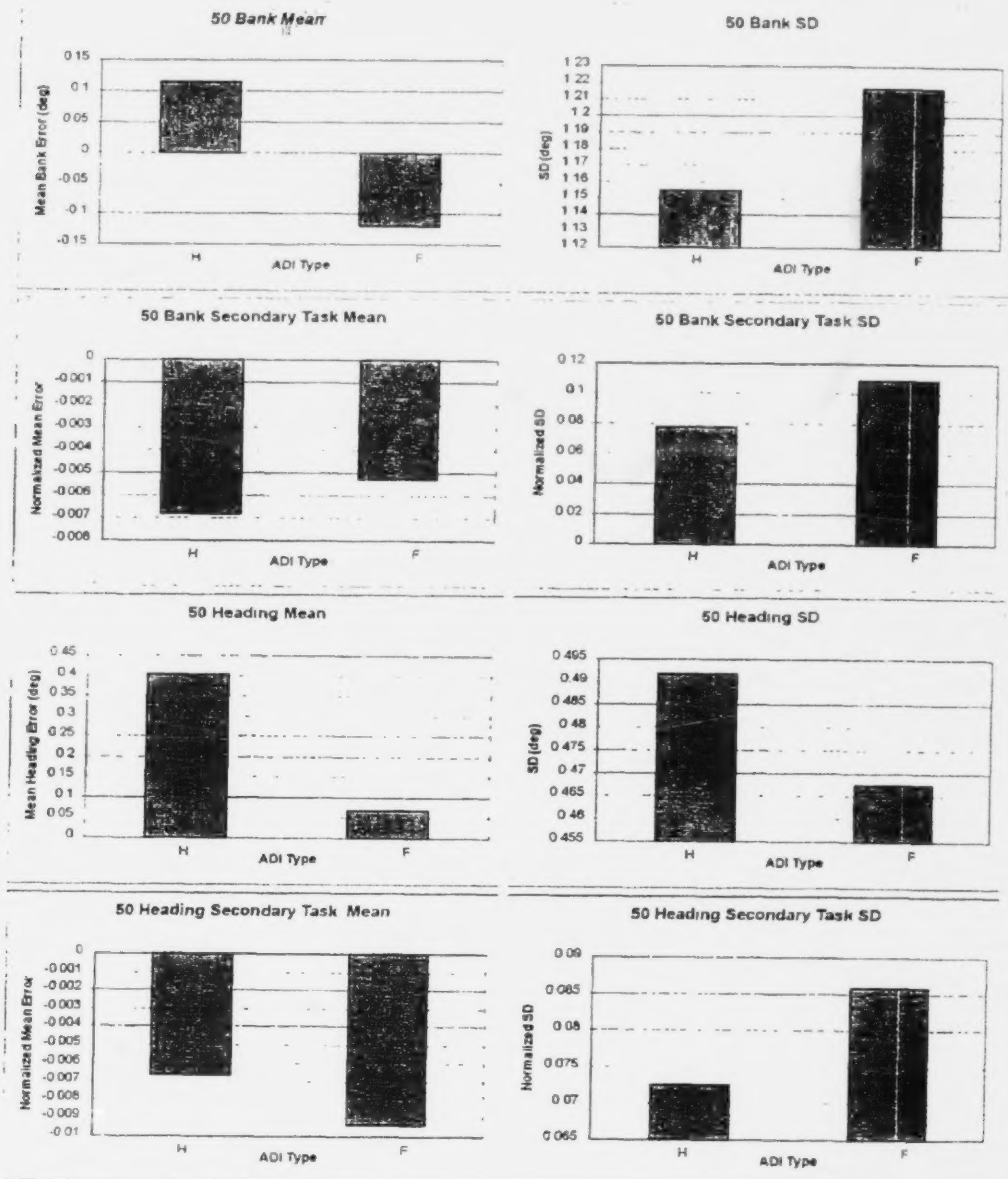
Comparison of Conventional vs. Frequency Separated Display ADI in 40 Degrees Turns



Bank refers to the bank error during bank turns, Heading refers to the heading error after banked turns Secondary task mean and SD have been normalized

Figure 6.1.9

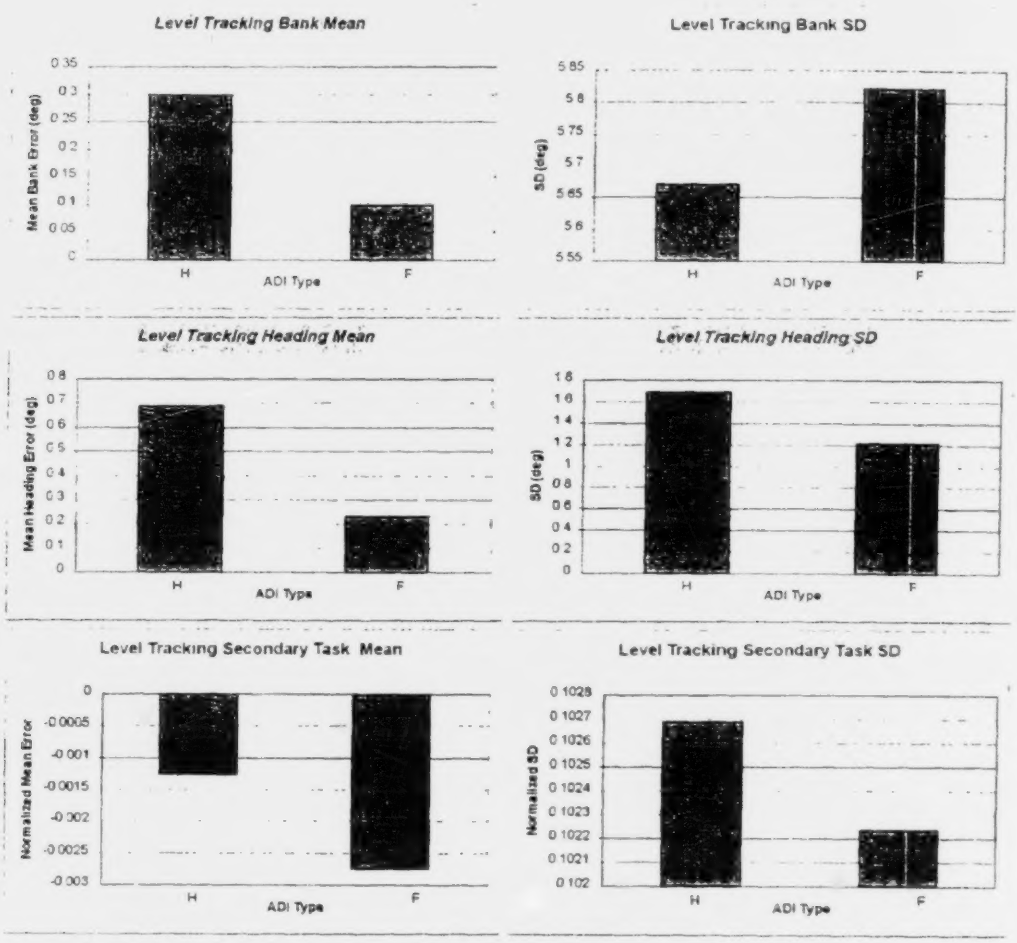
Comparison of Conventional vs. Frequency Separated Display ADI in 50 Degrees Turns



Bank refers to the bank error during bank turns, Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized

Figure 6.1.10

Comparison of Conventional vs. Frequency Separated Display ADI in Level Tracking



Level Tracking Bank Mean

Level Tracking Bank SD

Level Tracking Heading Mean

Level Tracking Heading SD

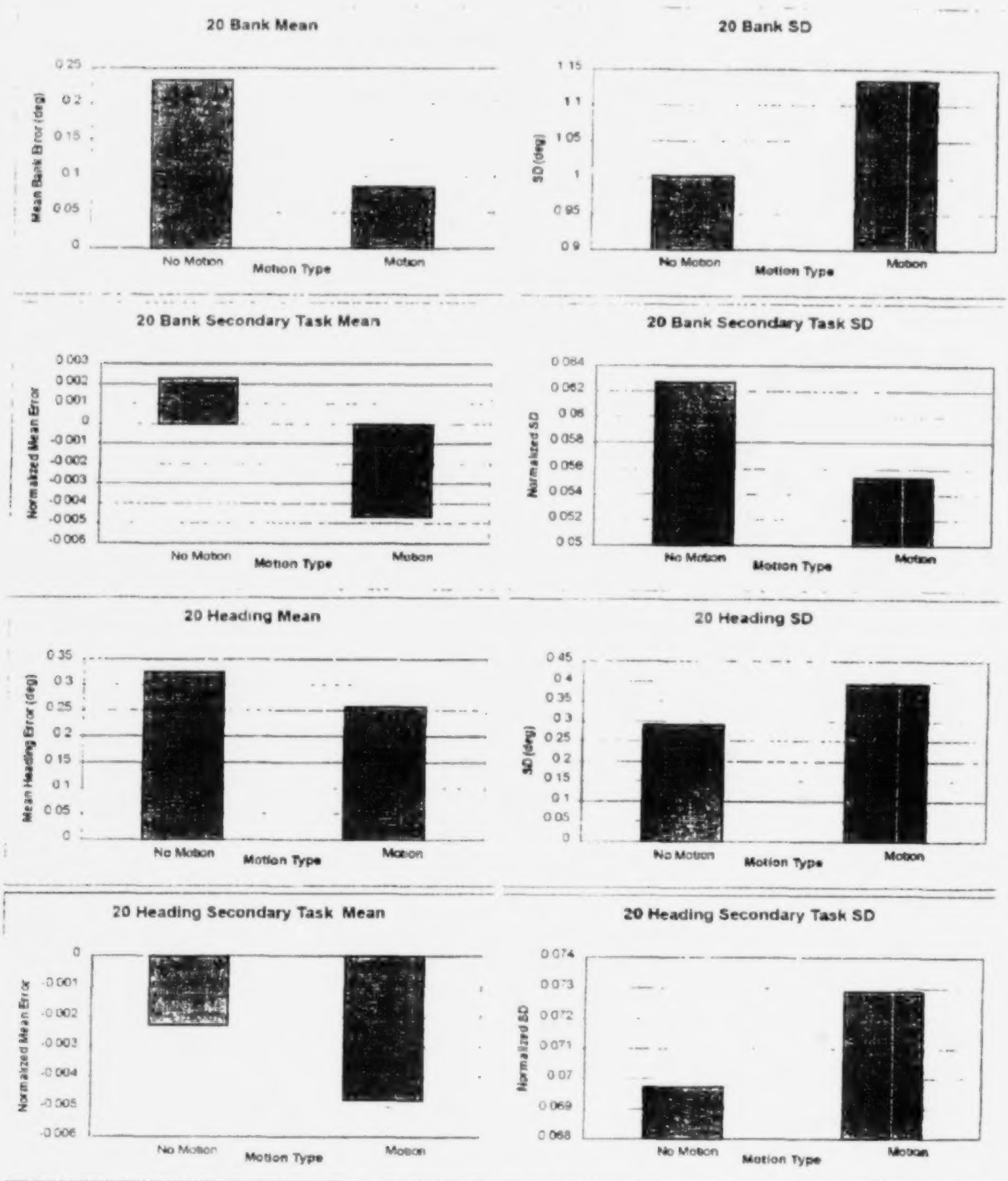
Level Tracking Secondary Task Mean

Level Tracking Secondary Task SD

Secondary task mean and SD have been normalized

Figure 6.1.11

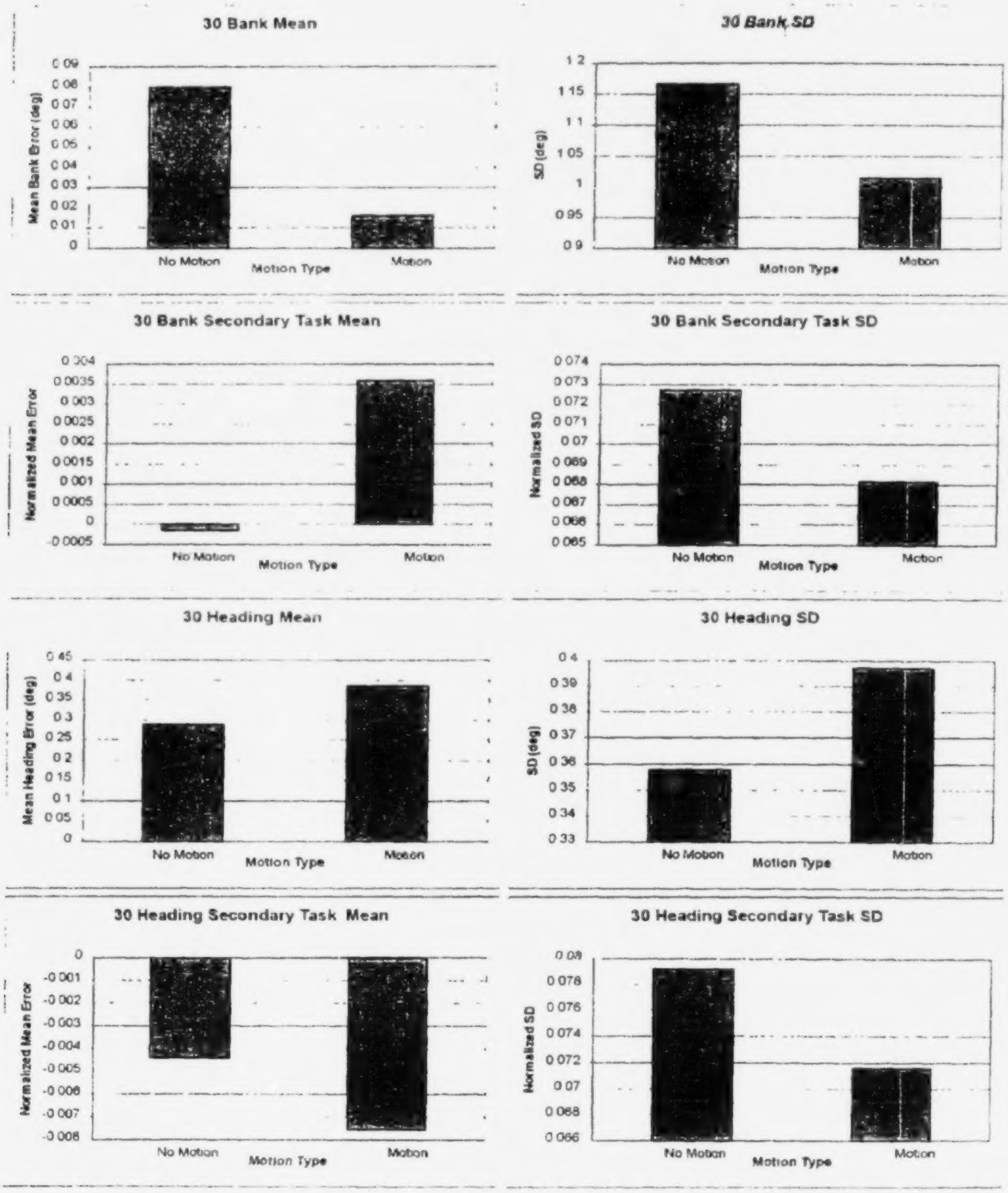
Comparison of No Motion vs. Motion in 20 Degrees Turns



Bank refers to the bank error during bank turns, Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized

Figure 6.1.12

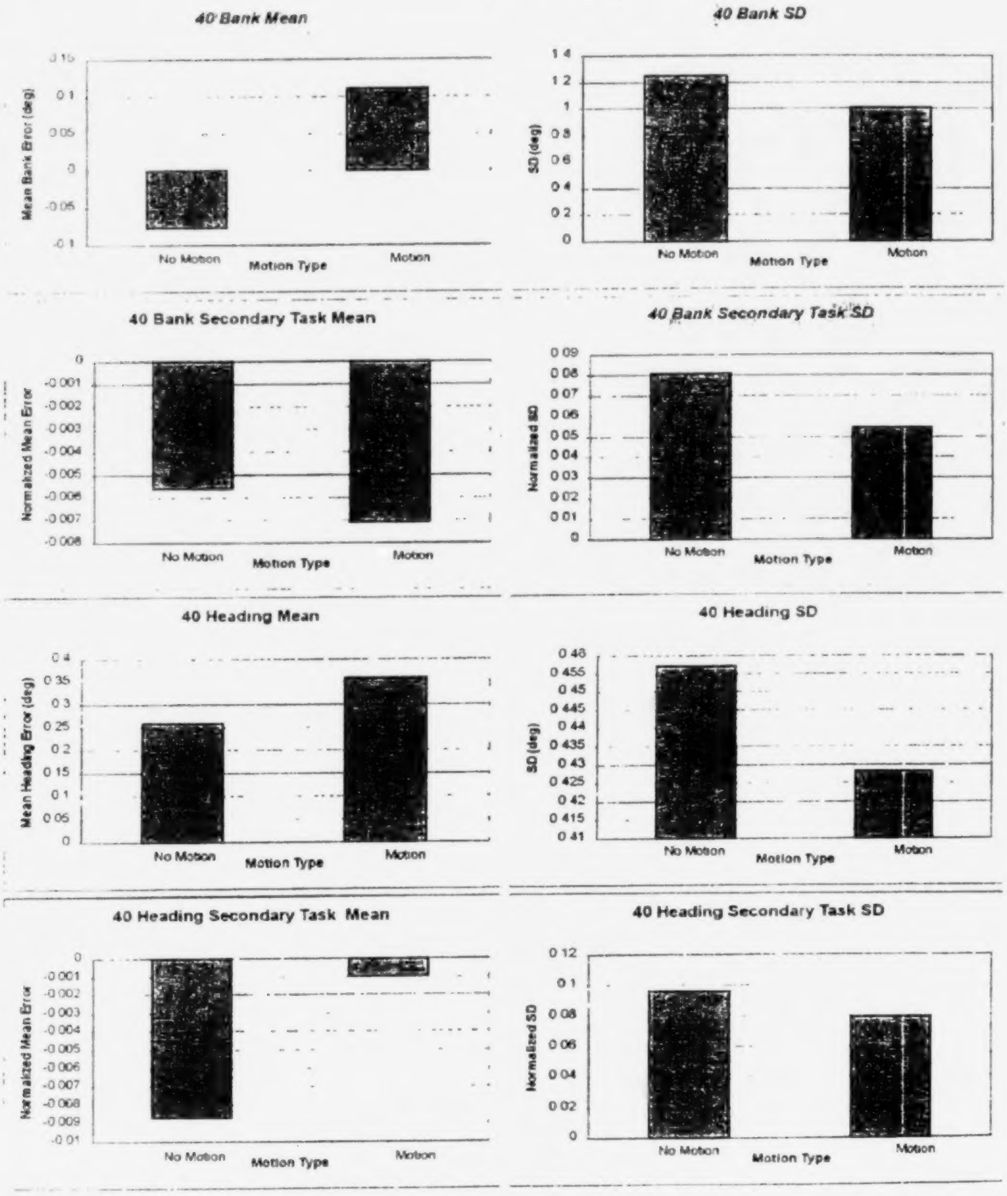
Comparison of No Motion vs. Motion in 30 Degrees Turns



Bank refers to the bank error during bank turns, Heading refers to the heading error after banked turns Secondary task mean and SD have been normalized

Figure 6.1.13

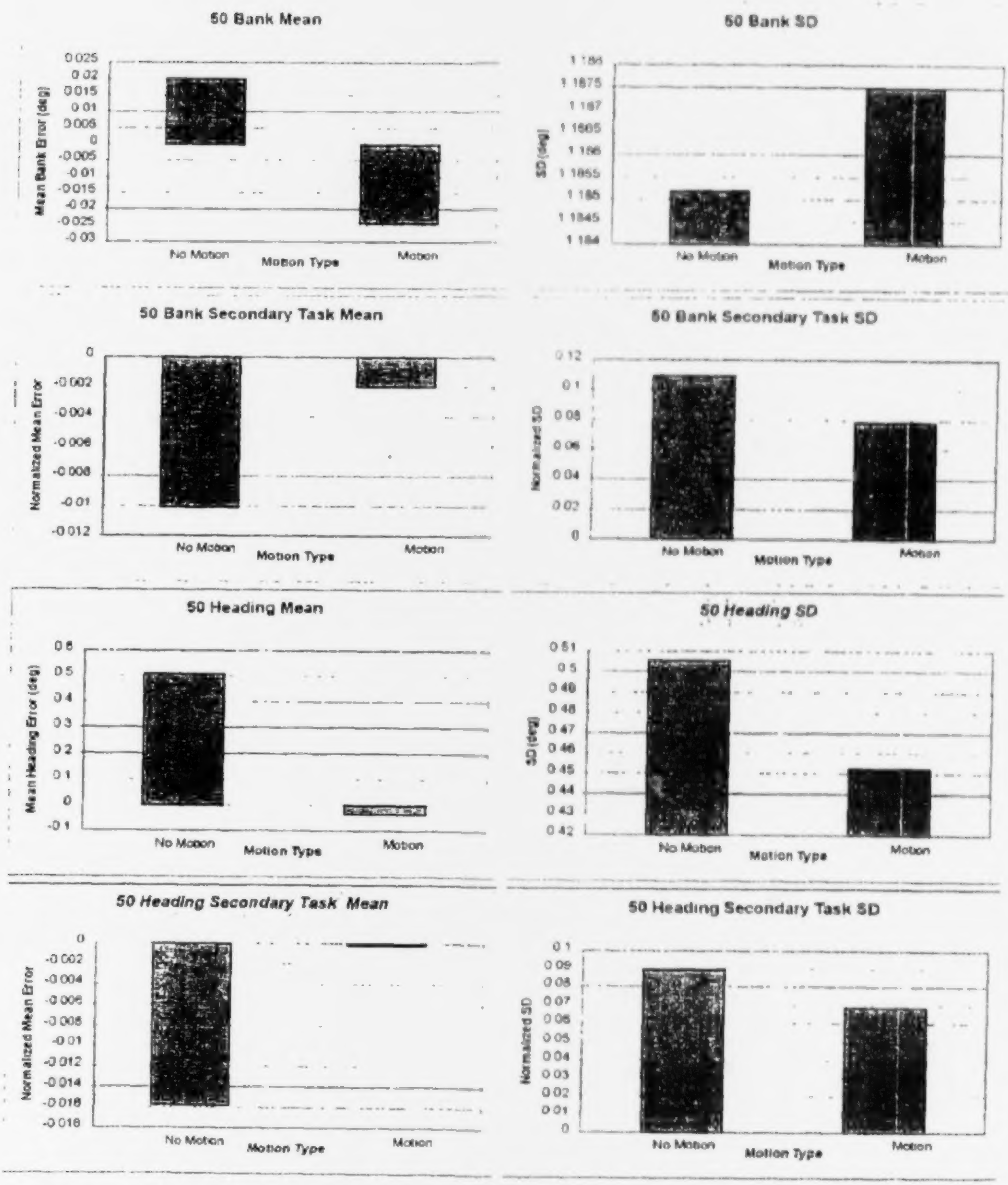
Comparison of No Motion vs. Motion in 40 Degrees Turns



Bank refers to the bank error during bank turns, Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized

Figure 6.1.14

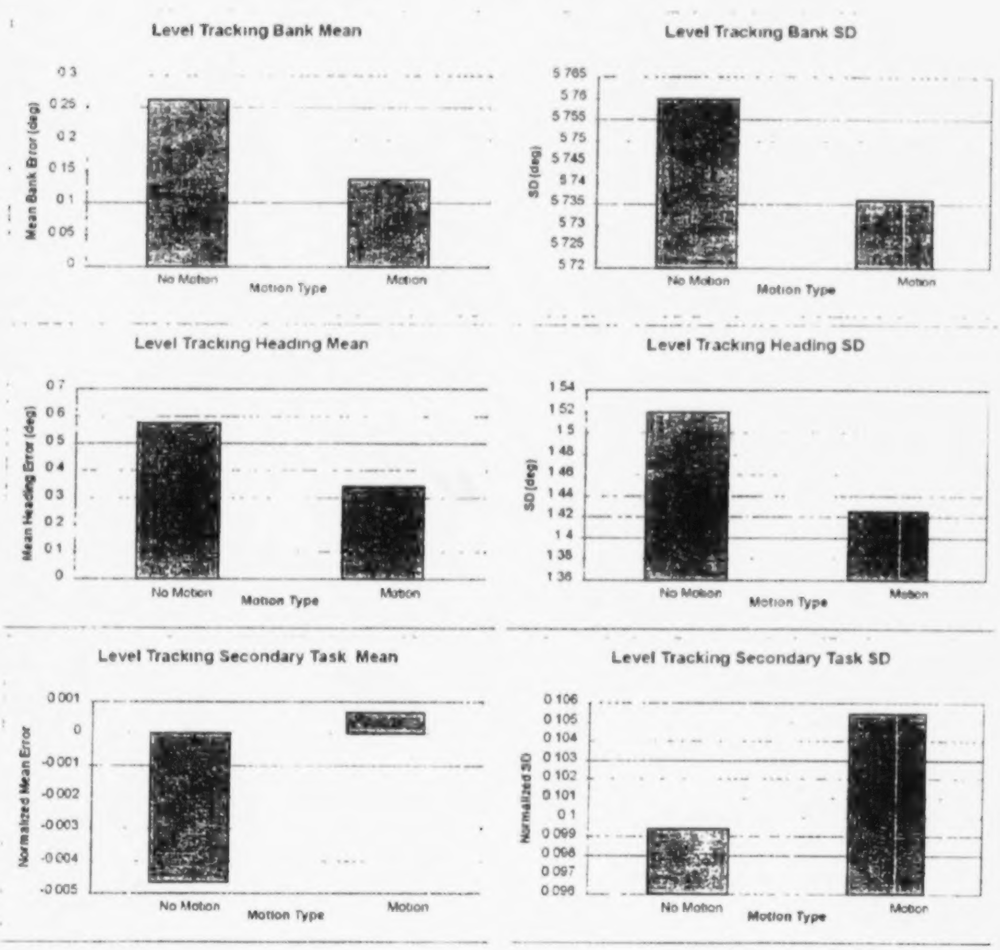
Comparison of No Motion vs. Motion in 50 Degrees Turns



Bank refers to the bank error during bank turns, Heading refers to the heading error after banked turns. Secondary task mean and SD have been normalized.

Figure 6.1.15

Comparison of No Motion vs. Motion in Level Tracking



Secondary task mean and SD have been normalized

Figure 6.2.1

Sample Time History of Sudden Attitude Upset Run Involving a Pilot Control Reversal

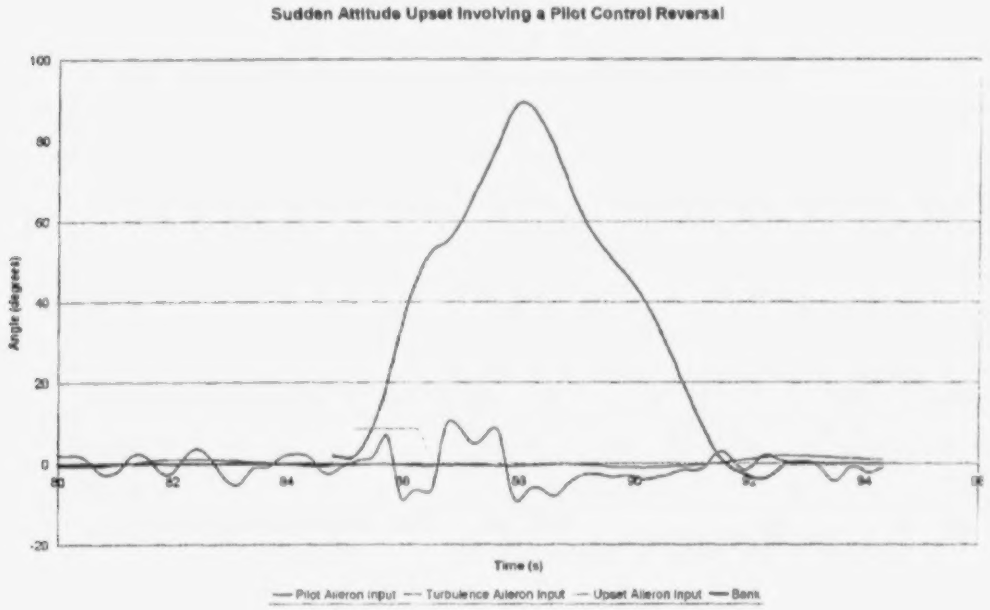


Figure 6.2.2

Sample Time History of Unusual Attitude Recovery Run Involving a Pilot Control Reversal

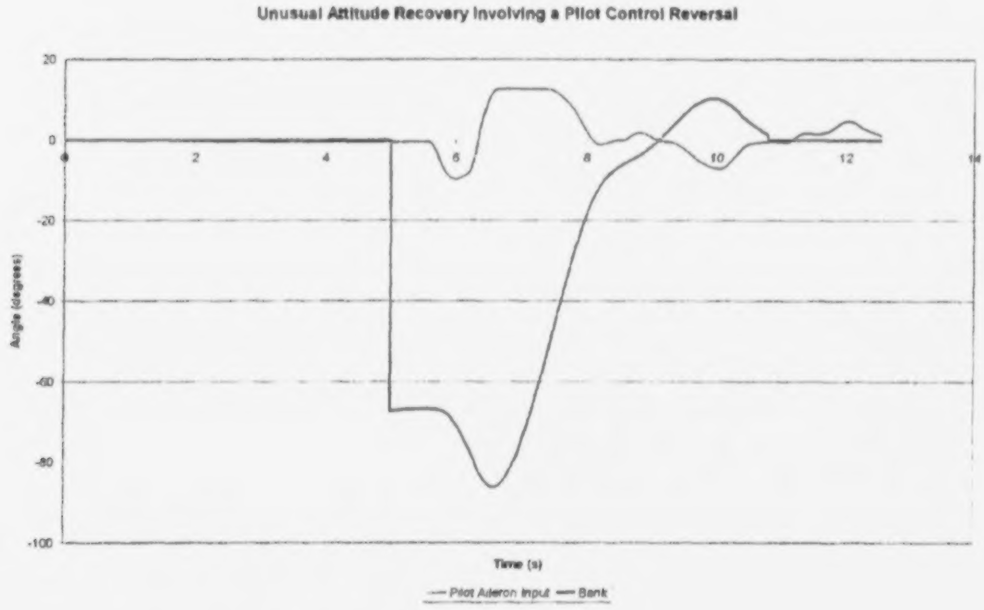


Figure 6.2.3

Plot of Correlation of Aileron Input and Turbulence versus Time

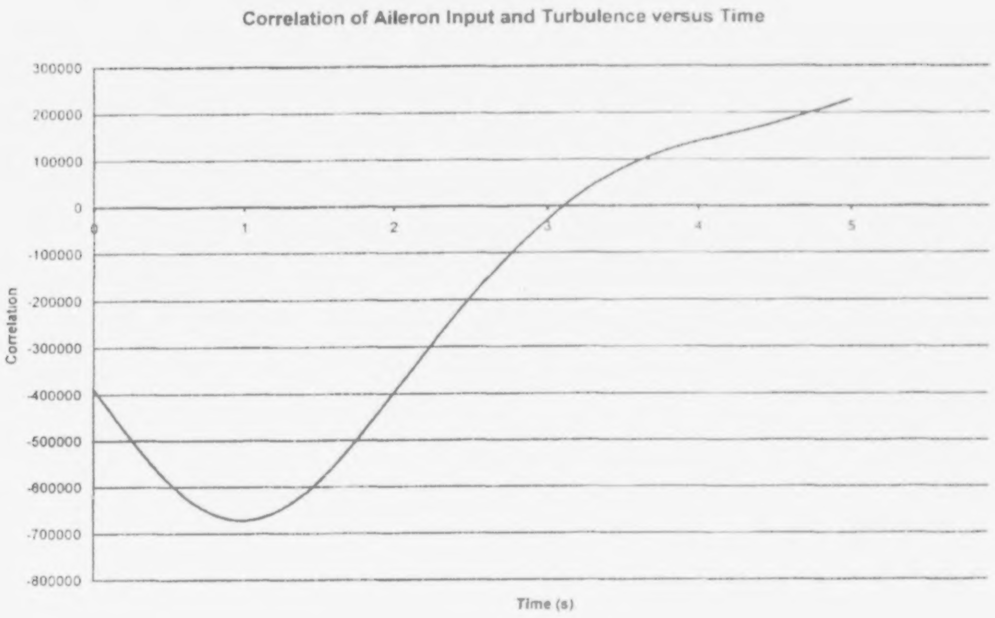


Figure 6.2.4

3-D Plot of Accumulated Aileron Inputs versus Time for Sudden Upset Task

Conventional Moving Horizon ADI

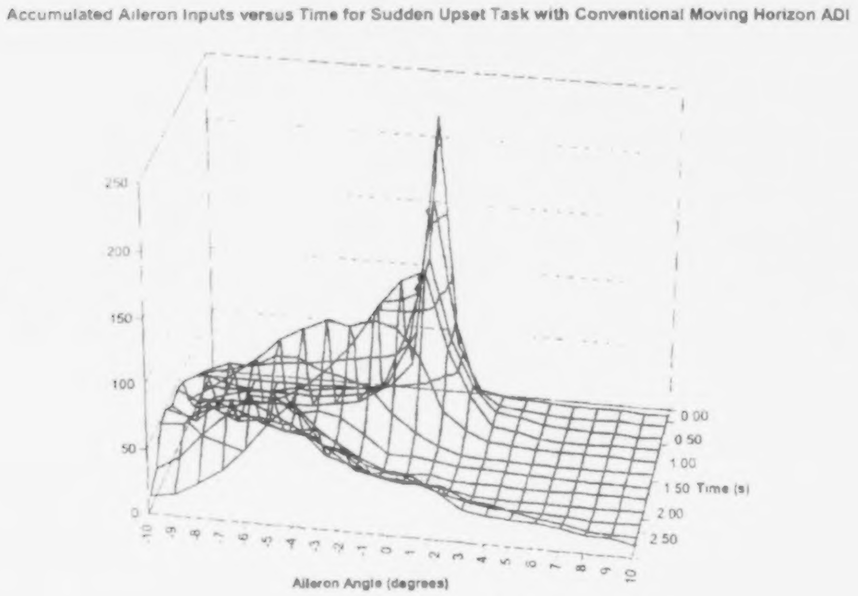


Figure 6.2.5

3-D Plot of Accumulated Aileron Inputs versus Time for Sudden Upset Task

Frequency Separated Display ADI

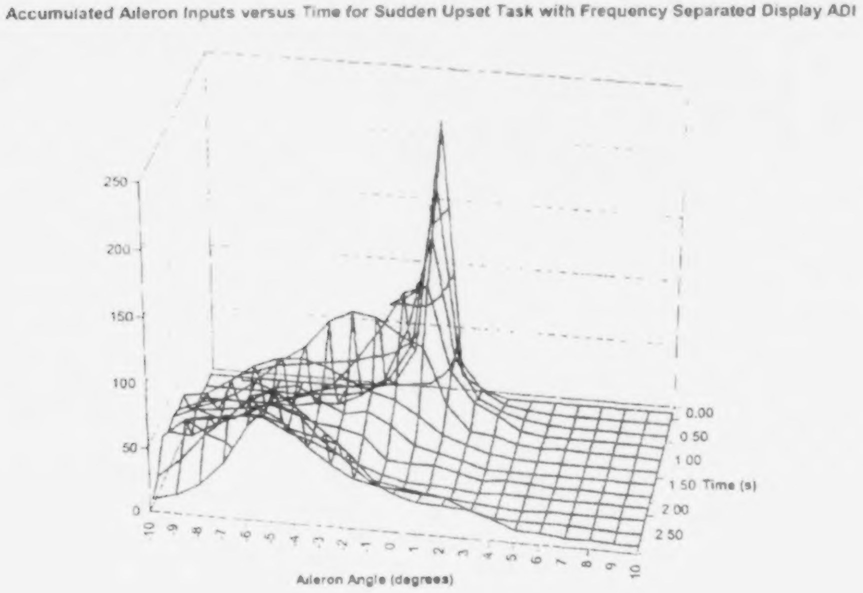


Figure 6.2.6

3-D Plot of Accumulated Aileron Inputs versus Time for Sudden Upset Task

Conventional Moving Horizon ADI (Zoomed In)

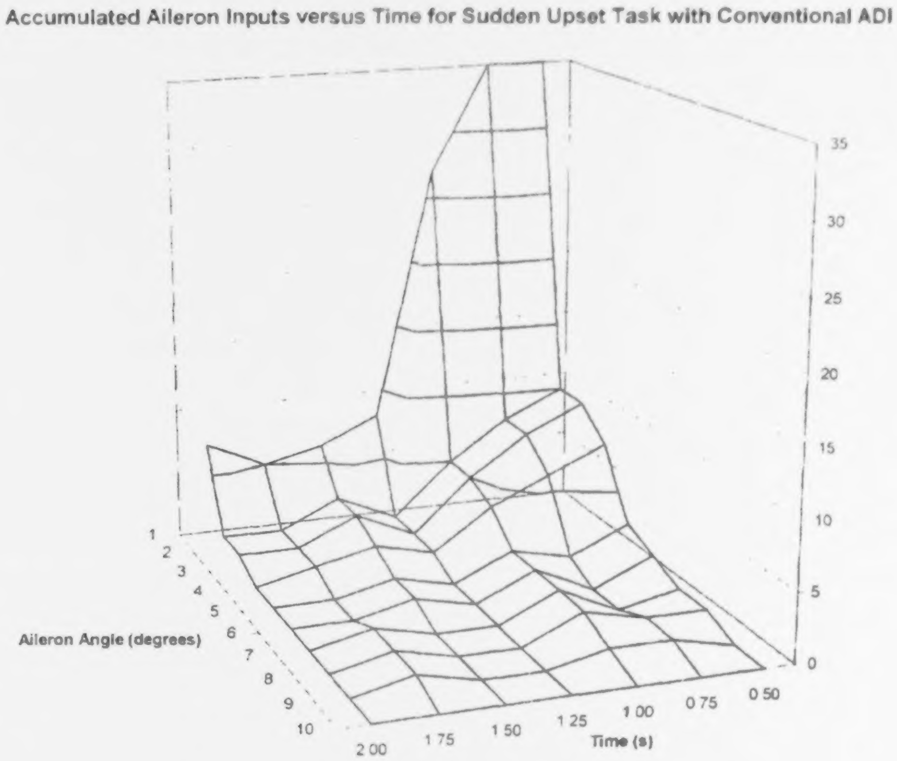
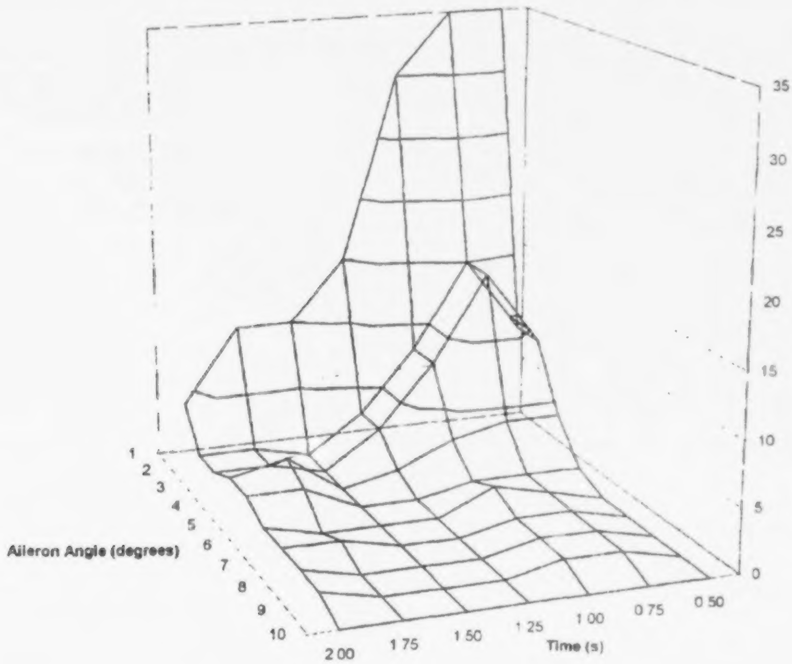


Figure 6.2.7

3-D Plot of Accumulated Aileron Inputs versus Time for Sudden Upset Task

Frequency Separated Display ADI (Zoomed In)



Accumulated Aileron Inputs versus Time for Sudden Upset Task with Frequency Separated ADI

Figure 6 2.8

3-D Plot of Accumulated Aileron Inputs versus Time for Unusual Attitude Recovery Task

Conventional Moving Horizon ADI

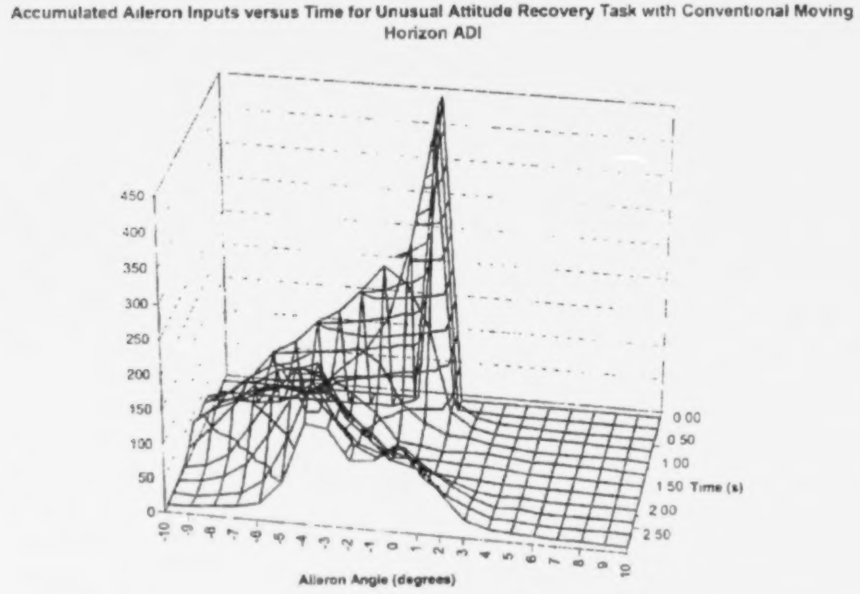


Figure 6.2.9

3-D Plot of Accumulated Aileron Inputs versus Time for Unusual Attitude Recovery Task

Frequency Separated Display ADI

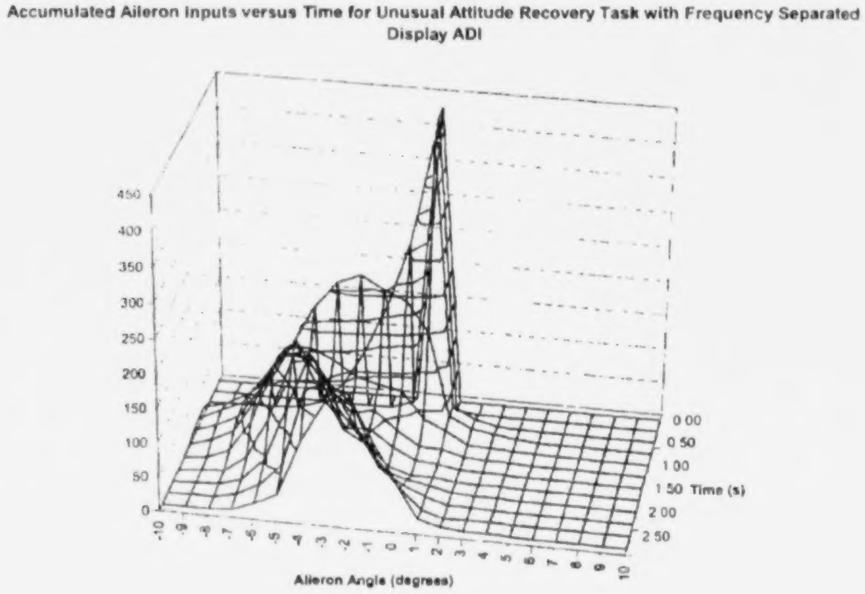


Figure 6.2.10

3-D Plot of Accumulated Aileron Inputs versus Time for Unusual Attitude Recovery Task Conventional Moving Horizon ADI (Zoomed In)

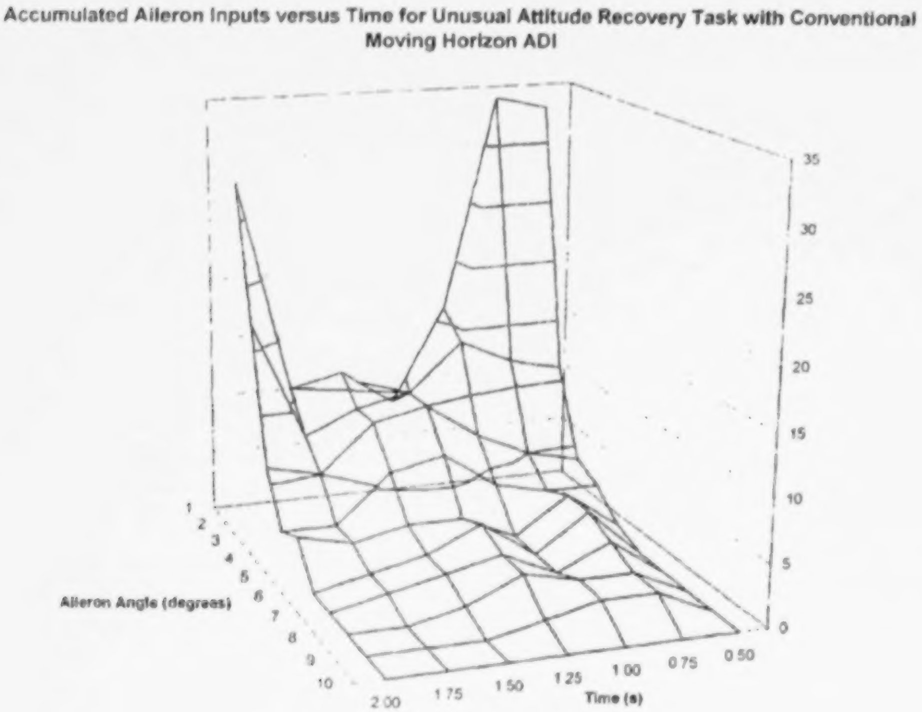


Figure 6.2.11

3-D Plot of Accumulated Aileron Inputs versus Time for Unusual Attitude Recovery Task

Frequency Separated Display ADI (Zoomed In)

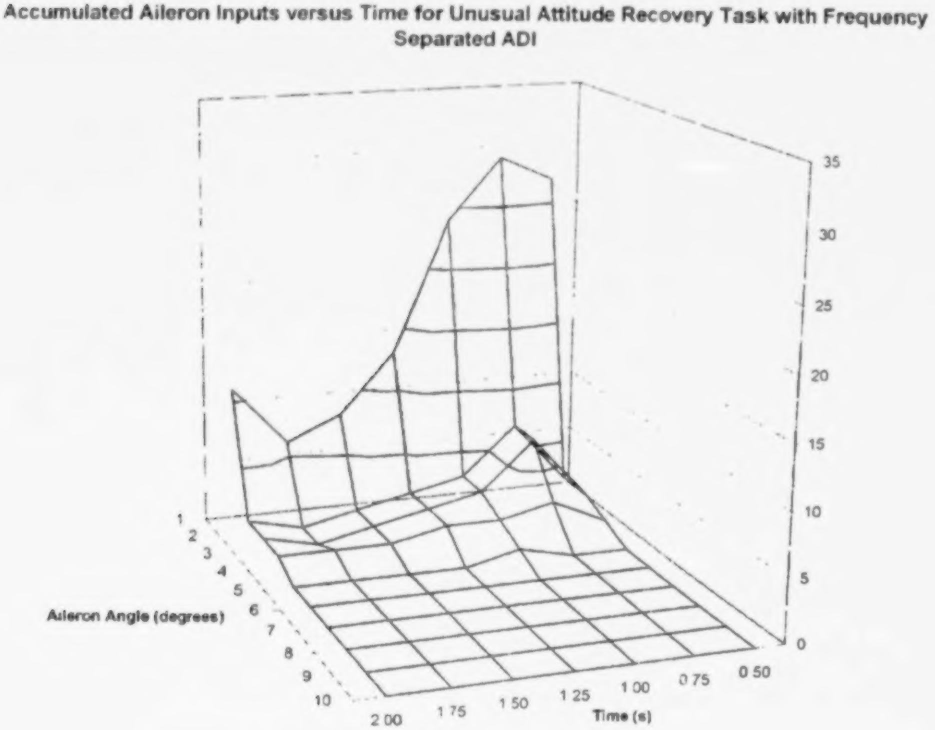


Figure 6.2.12

Contour Plot of Aileron Inputs versus Time for Sudden Upset Task

Conventional Moving Horizon ADI

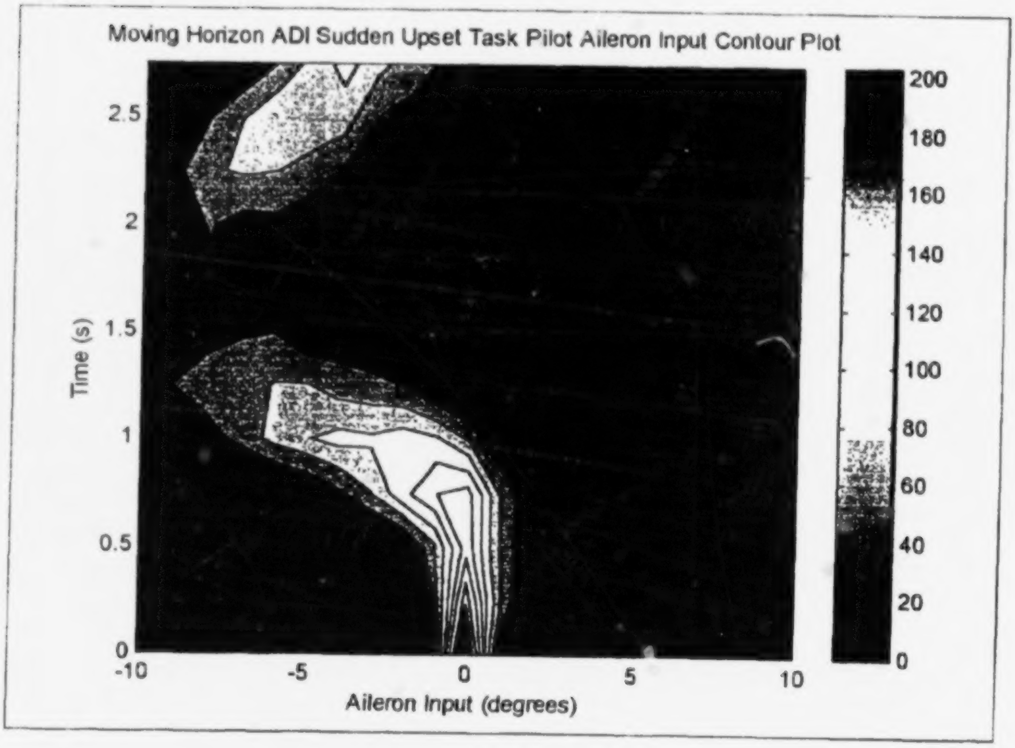


Figure 6.2.13

Contour Plot of Aileron Inputs versus Time for Sudden Upset Task

Frequency Separated Display ADI

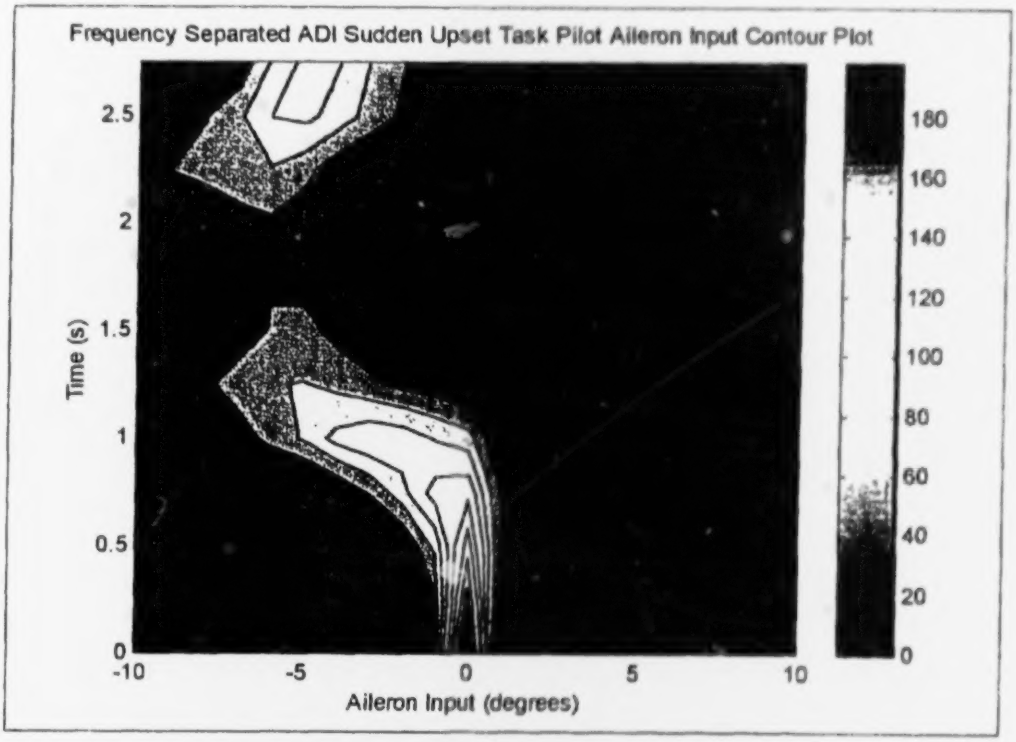


Figure 6.2.14

Contour Plot of Aileron Inputs versus Time for Unusual Attitude Recovery Task

Conventional Moving Horizon ADI

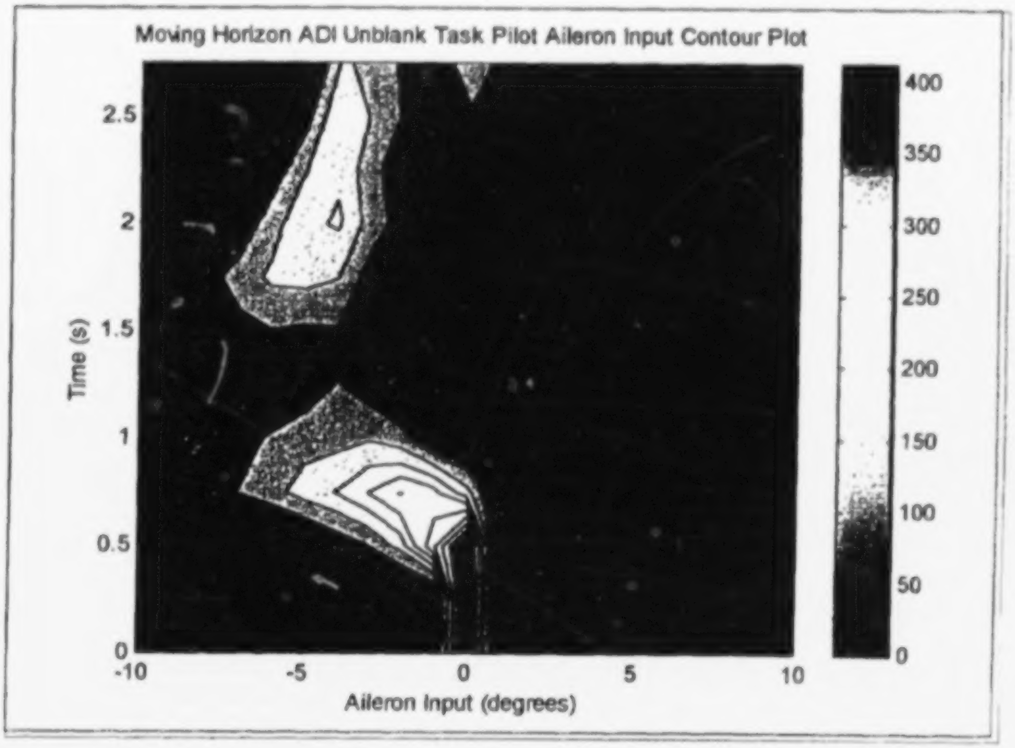


Figure 6.2.15

Contour Plot of Aileron Inputs versus Time for Unusual Attitude Recovery Task

Frequency Separated Display ADI

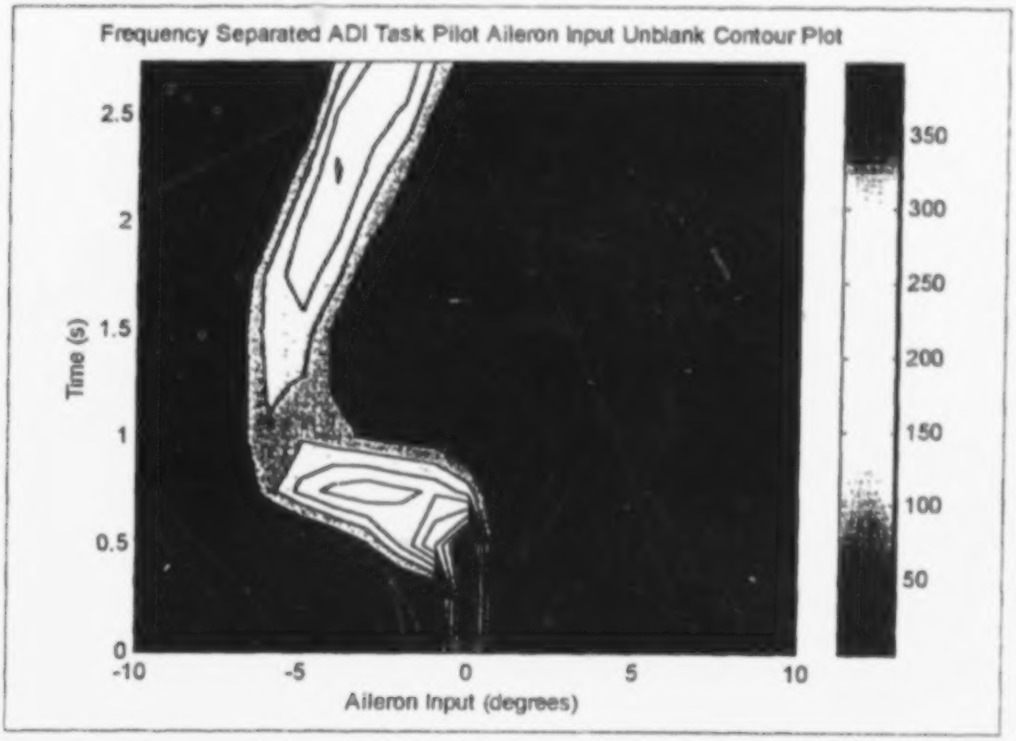


Figure 6.2.16

Distribution of Control Reversals in Sudden Attitude Upset Task

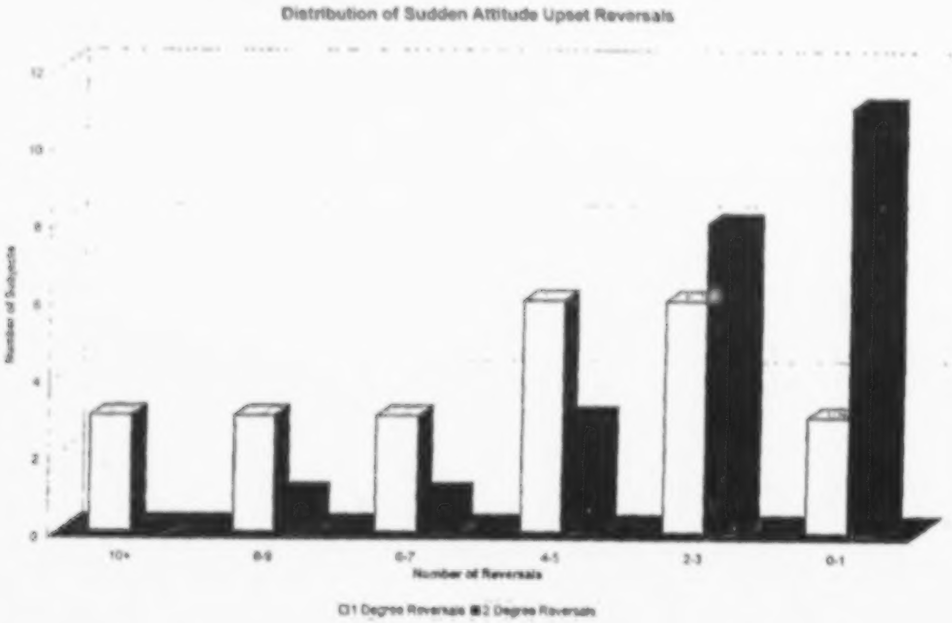


Figure 6.2.17

Distribution of Control Reversals in Unusual Attitude Recovery Task

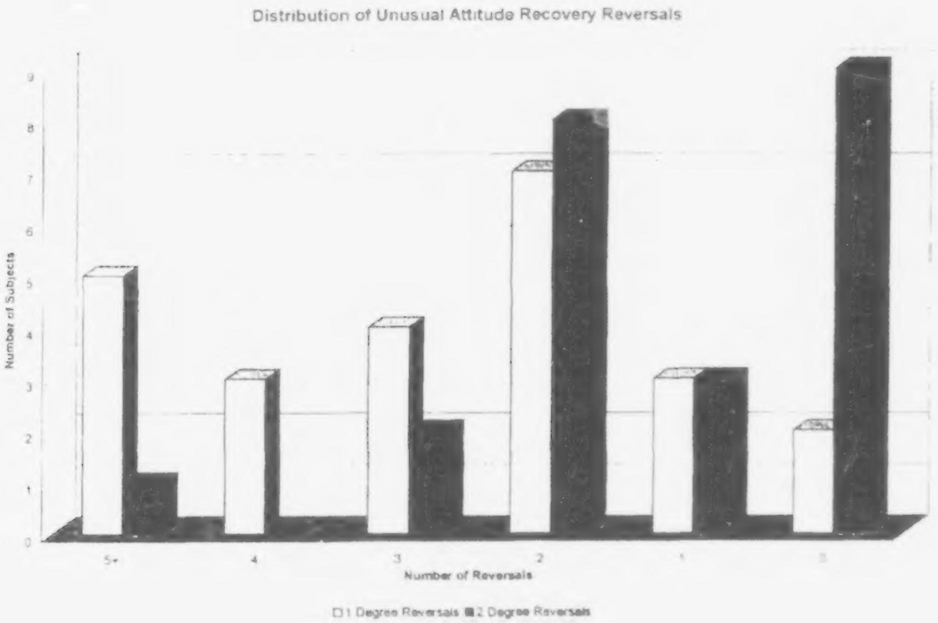


Figure 6.2.18

Control Reversals as a Function of Aileron Deflection in Sudden Attitude Upset Task

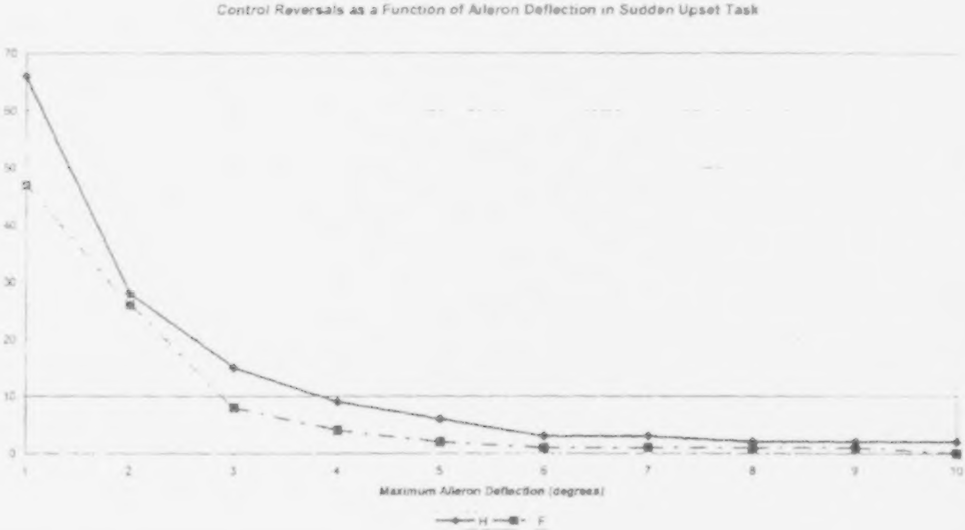


Figure 6.2.19

Control Reversals as a Function of Aileron Deflection in Unusual Attitude Recovery Task

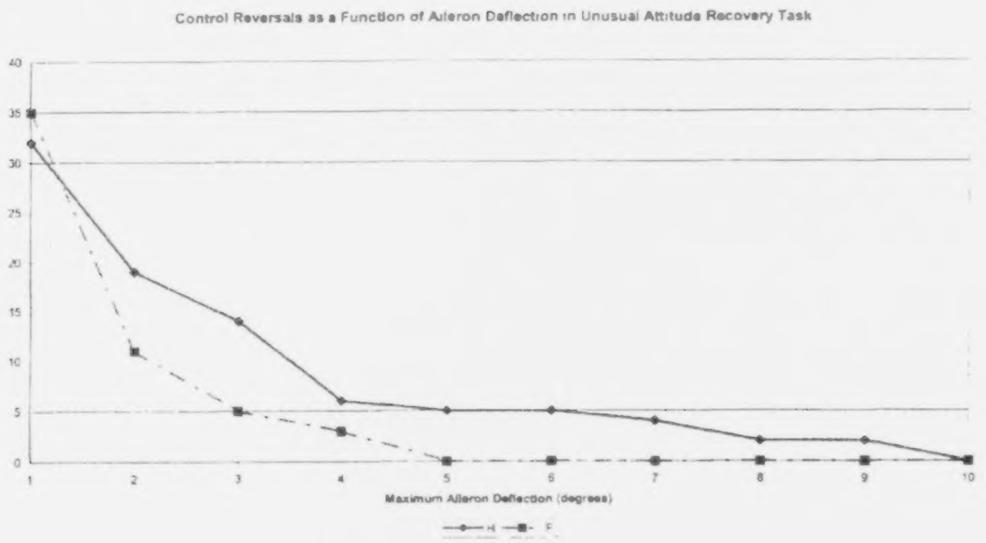


Figure 6.3.1

Average TLX Ratings

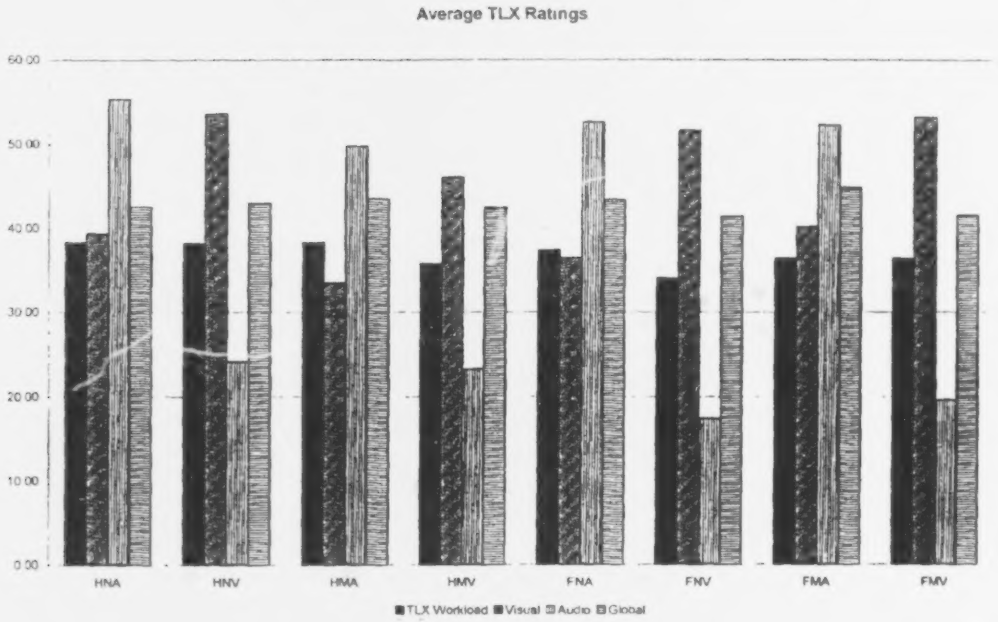


Figure 6.3.2

Average TLX Ratings for Conventional versus Frequency Separated Display ADI

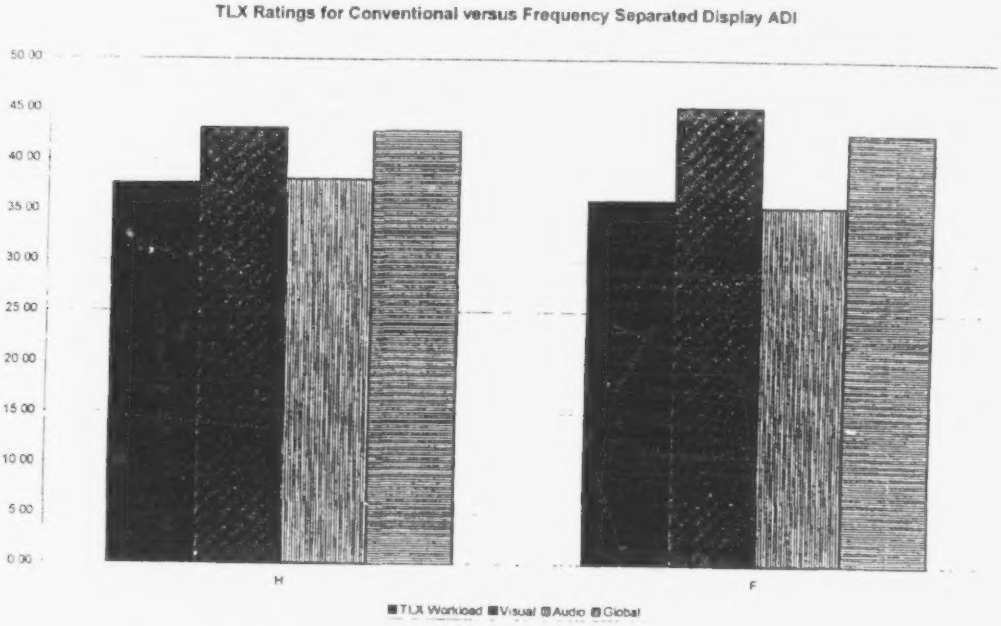


Figure 6 3.3

Average TLX Ratings for No Motion versus Motion

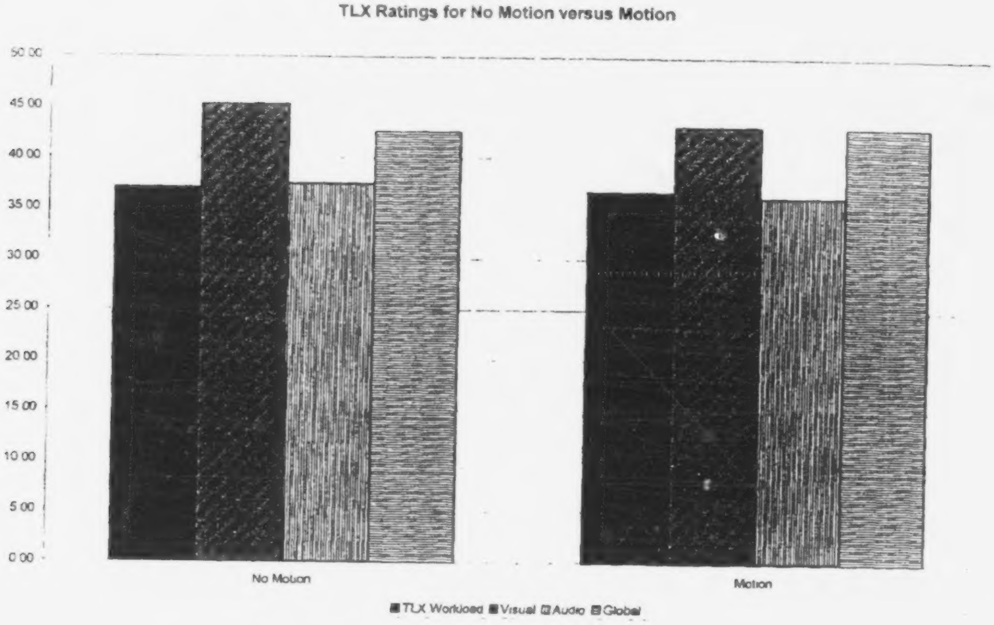
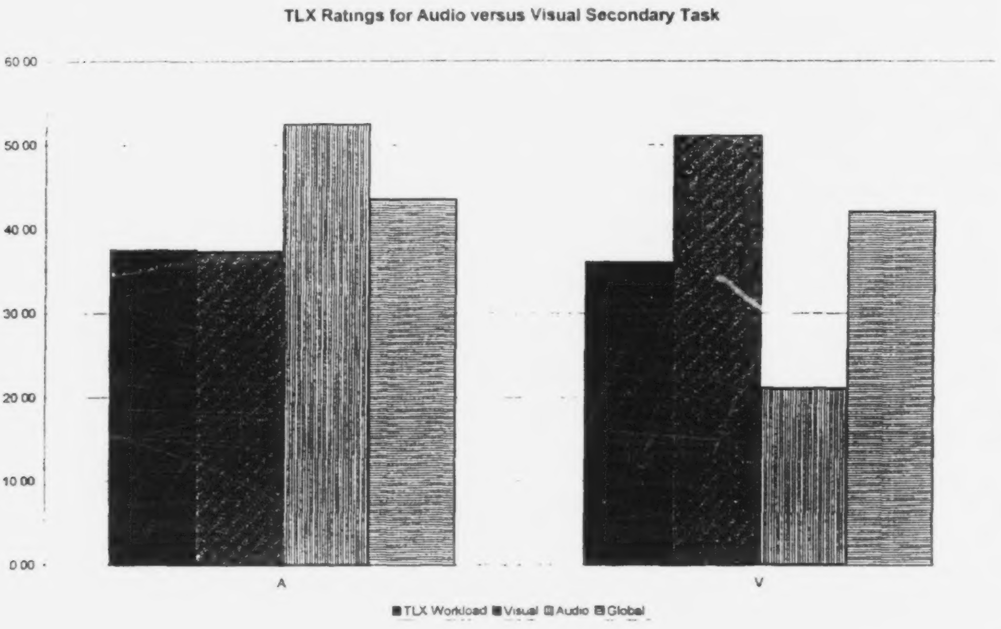


Figure 6.3.4

Average TLX Ratings for Audio versus Visual Secondary Task



7 Conclusions

This was an experiment designed to determine pilot performance while using two different types of ADI displays, as well as with and without simulator motion. Naïve subjects were selected to prevent bias due to previous experiences, and also allow transfer effects to be tested.

The UTIAS Flight Research Simulator was set up as a T-33 trainer jet with appropriate motion cues to facilitate this experiment. An EFIS display projected on a CRT screen provided the necessary cockpit instrumentation. Pilot control consisted of lateral control on the primary stick, as well as a small joystick for secondary task control. A variety of flight tasks were performed, which broadly consisted of two types: continuous events, and discrete events. These two types of events allowed analysis of pilot performance during routine flight manoeuvres and reaction to unexpected or unusual attitude events.

The experimental results suggest that ADI type did not have a significant effect on performance in commanded heading changes. However, there were measurable effects in the level tracking task, with significantly better performance while using the frequency separated display compared with the conventional ADI. Motion also improved pilot performance in all cases in which the analysis of variance showed motion to be significant at $P < 0.1$, with only one exception. However, due to the small number of cases where motion was significant, it is likely that simulator motion had little effect on pilot performance in the continuous tasks.

In terms of discrete events, fewer control reversals occurred while using the frequency separated display in all cases except the one degree criterion unusual attitude recovery case. There was a wide range in pilot performance, with the best results for both discrete tasks showing no reversals and the worst results showing reversals in 69% of the one degree criterion sudden upset tasks and in 31% of the one degree criterion unusual attitude recovery tasks. It was also observed through the contour plots that pilot aileron input was more consistent with less overshoot while using the frequency separated display. Pilots performed better when motion was present for the unusual attitude recoveries, but better by far when motion was absent for the sudden attitude upsets. It is unclear why this is the case.

The secondary tasks were sufficiently balanced as seen by similar performance while using either audio or visual tasks. Pilot preference varied on which task was easier to perform, so the choice in using both tasks and a relatively large number of test subjects was appropriate for this experiment.

In comparison with the past studies performed at the University of Illinois in the 1970's, the results of this experiment most closely resemble the results found in their in-flight experiments. In their flight experiments, it was shown that the frequency separated display provided at least equivalent pilot attitude tracking performance as the moving horizon display, while reducing the number of control reversals in the unusual attitude recoveries. This is similar to the findings of this experiment that showed improved performance while using the frequency separated ADI in level tracking, and reduced number of control reversals overall. The improved performance in commanded heading changes due to the use of the frequency separated display and simulator motion in their simulator studies were not observed in this experiment.

Overall, performance with the frequency separated display was generally either similar to or superior to that with the conventional ADI. No significant negative attributes were observed for the frequency separated display.

7.1 Suggestions

A number of changes to the experiment may have improved the quality of results acquired. These suggestions could be taken into consideration in further studies or other research of the same nature.

The overall workload of the test subjects was relatively low, as witnessed by the TLX ratings and subject comments. By increasing workload to a higher level, the stresses while using the different ADI displays or other experiment variables could be better observed. Increasing the workload could be accomplished either through increasing the difficulty of the primary tasks or the secondary task. The former is preferable since the goal is to analyse pilot performance in operating the aircraft. However, a longer training period, possibly with a ramp in difficulty would be required.

8 References

1. Roscoe, S. N., "Aviation Psychology", The Iowa State University Press, 1980.
2. Roscoe, S. N. "Design-Induced Errors." AeroNews Issue 1/96, http://www.aero.ca/News1_96.html.
3. Roscoe, S. N. "Horizon Control Reversals and the Graveyard Spiral." CSERIAC Gateway Volume VII: Number 3, 1997.
4. Johnson, S. L. and Roscoe S. N., "Frequency-Separated Flight Displays", Technical Report ONR-70-2, University of Illinois, Aviation Research Laboratory, Institute of Aviation, October 1970.
5. Johnson, S. L., "An Evaluation of the Principle of Frequency Separation for Aircraft Attitude Display", Technical Report ARL-71-17/ONR-71-2, University of Illinois, Aviation Research Laboratory, Institute of Aviation, August 1971.
6. Jacobs, R. S., Williges, R. C., and Roscoe, S. N., "Simulator Motion as a Factor In Flight-Director Display Evaluation", Technical Report ARL-72-1/ONR-72-1/AFOSR-72-1, University of Illinois, February 1972.
7. Roscoe, S. N. and Williges, R. C., "Motion Relationships in Aircraft Attitude and Guidance Displays: A Flight Experiment", Technical Report ARL-72-32/ONR-72-2, University of Illinois, December 1972.
8. Douvillier, J. G. Jr., Turner, H. L. and others, "Effects of Flight Simulator Motion on Pilots' Performance of Tracking Tasks", NASA Technical Note D-143, February 1960.
9. Stokes, A., Wickens, C. D. and Kite, K., "A Review of the Research on Aviation Display Technology", Aviation Research Laboratory, Institute of Aviation University of Illinois, December 1985.
10. Reising, J. M., Solz, T. J. Jr. and others, "New Cockpit Technology: Unique Opportunities for the Pilot", SPIE Volume 2219 Cockpit Displays: 1994.

11. Crabtree, M. S. and Shingledecker, C. A., "Secondary Task Workload Assessment Methodology", Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 17-19, 1983.

12. Reid, L. D., Lan, J. K. Y., Graf W. O., and Haycock B. C., "The Development of a Simulator for ADI Studies", Report for DCIEM Contract W7711-007640/001/TOR, 2000.

13. Heffley, R. K., and Jewell, W. F., "Aircraft Handling Qualities Data", NASA CR-2144, December 1972.

14. Reid, L. D., Haycock, B. C., et al, "Flight Dynamics for Helicopter Emergency Manoeuvres Trainer", prepared for DCIEM under contract W7711-9-7528/001/TOR, 2000.

15. Etkin, B., and Reid, L. C., "Dynamics of Flight, Stability and Control," John Wiley and Sons, New York, 1996.

16. NASA-TLX, "Task Load Index, Version 1.0", Human Performance Research Group, NASA Ames Research Center, Moffett Field, California, 1988.

Appendix A

General and Detailed Schedule for One Test Subject

General Schedule for One Test Subject

Hours	*Task*
0.5	Introduction and simulator demo
0.5	Simulator familiarization flight training
0.5	Motion training
0.5	First ADI introduction and demonstration
0.75	First ADI with Motion (Session 1)
0.75	First ADI with Motion (Session 2)
0.75	First ADI with Motion (Session 3)
0.75	First ADI with Motion (Session 4)
0.75	First ADI without Motion (Session 1)
0.75	First ADI without Motion (Session 2)
0.75	First ADI without Motion (Session 3)
0.75	First ADI without Motion (Session 4)
0.5	Second ADI introduction and demonstration
0.75	Second ADI with Motion (Session 1)
0.75	Second ADI with Motion (Session 2)
0.75	Second ADI with Motion (Session 3)
0.75	Second ADI with Motion (Session 4)
0.75	Second ADI without Motion (Session 1)
0.75	Second ADI without Motion (Session 2)
0.75	Second ADI without Motion (Session 3)
0.75	Second ADI without Motion (Session 4)

14.5 TOTAL HOURS

Detailed Schedule

Randomly Generated Schedule for CR
Block: HN

Session 1

Visual Secondary Task

Level Tracking
Turn Type 3
Level Tracking
Turn Type 12
Sudden Upset to the Left
Turn Type 8
Unusual Attitude to the Right
Unusual Attitude to the Right

Exit From Cockpit and Complete TLX

Session 2

Audio Secondary Task

Level Tracking
Turn Type 2
Level Tracking
Turn Type 6
Sudden Upset to the Right
Turn Type 10
Unusual Attitude to the Left
Unusual Attitude to the Left

Exit From Cockpit and Complete TLX

Session 3

Audio Secondary Task

Level Tracking
Turn Type 5
Level Tracking
Turn Type 11
Sudden Upset to the Right
Turn Type 4
Unusual Attitude to the Left
Unusual Attitude to the Left

Exit From Cockpit and Complete TLX

Session 4

Visual Secondary Task

Level Tracking
Turn Type 7
Sudden Upset to the Left
Turn Type 1
Level Tracking
Turn Type 9
Unusual Attitude to the Right
Unusual Attitude to the Right

Exit From Cockpit and Complete TLX

Refer to Runcodes Sheet for Corresponding Runcodes

Randomly Generated Schedule for CR
Block: HM

Session 1

Visual Secondary Task

Level Tracking
Turn Type 9
Level Tracking
Turn Type 5
Sudden Upset to the Left
Turn Type 1
Unusual Attitude to the Left
Unusual Attitude to the Left

Exit From Cockpit and Complete TLX

Session 2

Audio Secondary Task

Level Tracking
Turn Type 12
Sudden Upset to the Left
Turn Type 6
Level Tracking
Turn Type 2
Unusual Attitude to the Right
Unusual Attitude to the Left

Exit From Cockpit and Complete TLX

Session 3

Visual Secondary Task

Level Tracking
Turn Type 3
Level Tracking
Turn Type 7
Sudden Upset to the Right
Turn Type 10
Unusual Attitude to the Left
Unusual Attitude to the Right

Exit From Cockpit and Complete TLX

Session 4

Audio Secondary Task

Level Tracking
Turn Type 8
Level Tracking
Turn Type 4
Sudden Upset to the Right
Turn Type 11
Unusual Attitude to the Right
Unusual Attitude to the Right

Exit From Cockpit and Complete TLX

Refer to Runcodes Sheet for Corresponding Runcodes

Randomly Generated Schedule for CR
Block: FM

Session 1

Audio Secondary Task

Level Tracking
Turn Type 5
Level Tracking
Turn Type 3
Sudden Upset to the Left
Turn Type 10
Unusual Attitude to the Left
Unusual Attitude to the Right

Exit From Cockpit and Complete TLX

Session 2

Visual Secondary Task

Level Tracking
Turn Type 11
Sudden Upset to the Left
Turn Type 4
Level Tracking
Turn Type 8
Unusual Attitude to the Left
Unusual Attitude to the Left

Exit From Cockpit and Complete TLX

Session 3

Visual Secondary Task

Level Tracking
Turn Type 2
Level Tracking
Turn Type 6
Sudden Upset to the Right
Turn Type 9
Unusual Attitude to the Right
Unusual Attitude to the Right

Exit From Cockpit and Complete TLX

Session 4

Audio Secondary Task

Level Tracking
Turn Type 1
Level Tracking
Turn Type 7
Sudden Upset to the Right
Turn Type 12
Unusual Attitude to the Right
Unusual Attitude to the Left

Exit From Cockpit and Complete TLX

Refer to Runcodes Sheet for Corresponding Runcodes

Randomly Generated Schedule for CR
Block: FN

Session 1

Audio Secondary Task

Level Tracking
Turn Type 4
Sudden Upset to the Left
Turn Type 7
Level Tracking
Turn Type 10
Unusual Attitude to the Left
Unusual Attitude to the Left

Exit From Cockpit and Complete TLX

Session 2

Visual Secondary Task

Level Tracking
Turn Type 3
Sudden Upset to the Right
Turn Type 8
Level Tracking
Turn Type 11
Unusual Attitude to the Right
Unusual Attitude to the Right

Exit From Cockpit and Complete TLX

Session 3

Visual Secondary Task

Level Tracking
Turn Type 12
Sudden Upset to the Left
Turn Type 1
Level Tracking
Turn Type 5
Unusual Attitude to the Right
Unusual Attitude to the Left

Exit From Cockpit and Complete TLX

Session 4

Audio Secondary Task

Level Tracking
Turn Type 6
Level Tracking
Turn Type 9
Sudden Upset to the Right
Turn Type 2
Unusual Attitude to the Right
Unusual Attitude to the Left

Exit From Cockpit and Complete TLX

Refer to Runcodes Sheet for Corresponding Runcode

Appendix B

TURING Computer Code for Random Schedule Generation Program

```
var bl1, bl2, bl3, bl4, first, second, g, h,
i, j : int
var r_type, sectask1, sectask2, OutStream,
passed : int
var name, block, filename : string
var used : array 1 .. 12 of int
var left_up, right_up, left_un, right_un :
int
var cur_sec : int % current sec task, 0 =
aud, 1 = vis
var secname : string

for count : 1 .. 12
    used (count) := 0
end for

randomize ()

left_up := 0
right_up := 0
left_un := 0
right_un := 0

cls
put "Please enter test subject name/initials
(up to 5 characters): " ..
get name
put "Please enter current test block (HN,
HM, FN, FM): " ..
get block
filename := name + "_" + block + ".txt"
put "Filename generated is ", filename
open : OutStream, filename, put

if OutStream = 0 then
    put "Error opening file"
end if
put ""
put "Generating runs..."
setscreen ("noecho")
put   :   OutStream,   "Randomly   Generated
Schedule for ", name
put : OutStream, "Block: ", block
put : OutStream, ""
put : OutStream, ""

randint (sectask1, 1, 2)
randint (sectask2, 1, 2)

if block = "HN" then
    for counter : 1 .. 4
        put : OutStream, "Session ", counter
        put : OutStream, ""
        if counter = 1 then
            if sectask1 = 1 then
                put   :   OutStream,   "Audio
Secondary Task"
                cur_sec := 0
            else
                put   :   OutStream,   "Visual
Secondary Task"
                cur_sec := 1
            end if
        elsif counter = 2 then
            if sectask1 = 2 then
                put   :   OutStream,   "Audio
Secondary Task"
                cur_sec := 0
            else
                put   :   OutStream,   "Visual
Secondary Task"
                cur_sec := 1
            end if
        elsif counter = 3 then
            if sectask2 = 1 then
                put   :   OutStream,   "Audio
Secondary Task"
                cur_sec := 0
            else
                put   :   OutStream,   "Visual
Secondary Task"
                cur_sec := 1
            end if
        else
            if sectask2 = 2 then
                put   :   OutStream,   "Audio
Secondary Task"
                cur_sec := 0
            else
                put   :   OutStream,   "Visual
Secondary Task"
                cur_sec := 1
            end if
        end if
        put : OutStream, ""
        if cur_sec = 0 then
            secname := "Aud"
        else
            secname := "Vis"
        end if

        if cur_sec = 0 then
            put : OutStream, block, counter,
secname, "-Level ", name, "311"
        else
            put : OutStream, block, counter,
secname, "-Level ", name, "315"
        end if

        randint (bl1, 1, 4)
        randint (bl2, 5, 8)
        randint (bl3, 9, 12)
        randint (first, 1, 3)
        randint (second, 1, 2)
        randint (g, 1, 2)
        randint (h, 1, 2)
        randint (i, 1, 2)
        randint (j, 1, 2)

        passed := 0
        loop
            if used (bl1) = 1 then
                bl1 := bl1 + 1
                if bl1 = 5 then
                    bl1 := 1
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        passed := 0
        loop
            if used (bl2) = 1 then
                bl2 := bl2 + 1
                if bl2 = 9 then
                    bl2 := 5
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        passed := 0
        loop
            if used (bl3) = 1 then
                bl3 := bl3 + 1
                if bl3 = 13 then
                    bl3 := 9
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        if first = 1 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1,
                    " ", name, bl1 + 10, "1"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1,
                    " ", name, bl1 + 10, "5"
            end if
            used (bl1) := used (bl1) + 1
            if g = 1 then
                if left_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "512"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "520"
                    end if
                    right_up := right_up + 1
                elsif right_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "511"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "519"
                    end if
                    left_up := left_up + 1
                else
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "511"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "519"
                        end if
                        left_up := left_up +
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "512"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "520"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "311"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "315"
                end if
            end if
            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "1"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "5"
                end if
                used (bl2) := used (bl2) + 1
                r_type := 3
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "1"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "5"
                end if
                used (bl3) := used (bl3) + 1
                r_type := 2
            end if
        elsif first = 2 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "1"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "5"
```

```
             end if
             used (bl2) := used (bl2) + 1
             if g = 1 then
                 if left_up = 2 then
                     if cur_sec = 0 then
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetRight ",
                             name, "512"
                     else
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetRight ",
                             name, "520"
                     end if
                     right_up := right_up + 1
                 elsif right_up = 2 then
                     if cur_sec = 0 then
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetLeft ",
                             name, "511"
                     else
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetLeft ",
                             name, "519"
                     end if
                     left_up := left_up + 1
                 else
                     if h = 1 then
                         if cur_sec = 0 then
                             put : OutStream,
block, counter, secname,
                                 "-UpsetLeft
",
                                 name, "511"
                         else
                             put : OutStream,
block, counter, secname,
                                 "-UpsetLeft
",
                                 name, "519"
                         end if
                         left_up := left_up +
1
                     else
                         if cur_sec = 0 then
                             put : OutStream,
block, counter, secname,
                                 "-UpsetRight
",
                                 name, "512"
                         else
                             put : OutStream,
block, counter, secname,
                                 "-UpsetRight
",
                                 name, "520"
                         end if
                         right_up := right_up
+ 1
                     end if
                 end if
             else
                 if cur_sec = 0 then
                     put : OutStream, block,
counter, secname, "-Level ",
                         name, "311"
                 else
                     put  :  OutStream,  block,
counter, secname, "-Level ",
                         name, "315"
                 end if
             end if

             if second = 1 then
                 if cur_sec = 0 then
                     put  :  OutStream,  block,
counter, secname, "-Turn", bl1,
                         " ",
                         name, bl1 + 10, "1"
                 else
                     put  :  OutStream,  block,
counter, secname, "-Turn", bl1,
                         " ",
                         name, bl1 + 10, "5"
                 end if
                 used (bl1) := used (bl1) + 1
                 r_type := 3
             else
                 if cur_sec = 0 then
                     put  :  OutStream,  block,
counter, secname, "-Turn", bl3,
                         " ",
                         name, bl3 + 10, "1"
                 else
                     put  :  OutStream,  block,
counter, secname, "-Turn", bl3,
                         " ",
                         name, bl3 + 10, "5"
                 end if
                 used (bl3) := used (bl3) + 1
                 r_type := 1
             end if
         else
             if cur_sec = 0 then
                 put   :   OutStream,   block,
counter, secname, "-Turn", bl3, " ",
                     name, bl3 + 10, "1"
             else
                 put   :   OutStream,   block,
counter, secname, "-Turn", bl3, " ",
                     name, bl3 + 10, "5"
             end if
             used (bl3) := used (bl3) + 1
             if g = 1 then
                 if left_up = 2 then
                     if cur_sec = 0 then
                         put    :    OutStream,
block, counter, secname,
                             "-UpsetRight ",
                             name, "512"
                     else
                         put    :    OutStream,
block, counter, secname,
                             "-UpsetRight ",
                             name, "520"
                     end if
                     right_up := right_up + 1
                 elsif right_up = 2 then
                     if cur_sec = 0 then
                         put    :    OutStream,
block, counter, secname,
                             "-UpsetLeft ",
                             name, "511"
                     else
                         put    :    OutStream,
block, counter, secname,
                             "-UpsetLeft ",
                             name, "519"
```

```
                    end if
                    left_up := left_up + 1
                else
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "511"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "519"
                        end if
                        left_up := left_up +
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "512"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "520"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "311"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "315"
                end if
            end if

            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "1"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "5"
                end if
                used (bl1) := used (bl1) + 1
                r_type := 2
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "1"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "5"
                end if
                used (bl2) := used (bl2) + 1
                r_type := 1
            end if
        end if

        if g = 2 then
            if left_up = 2 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-UpsetRight ",
                        name, "512"
                else
                    put : OutStream, block,
counter, secname, "-UpsetRight ",
                        name, "520"
                end if
                right_up := right_up + 1
            elsif right_up = 2 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-UpsetLeft ",
                        name, "511"
                else
                    put : OutStream, block,
counter, secname, "-UpsetLeft ",
                        name, "519"
                end if
                left_up := left_up + 1
            else
                if h = 1 then
                    if cur_sec = 0 then
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "511"
                    else
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "519"
                    end if
                    left_up := left_up + 1
                else
                    if cur_sec = 0 then
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "512"
                    else
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "520"
                    end if
                    right_up := right_up + 1
                end if
            end if
        else
            if cur_sec = 0 then
                put    :    OutStream,    block,
counter, secname, "-Level ", name,
                    "311"
            else
                put    :    OutStream,    block,
counter, secname, "-Level ", name,
                    "315"
            end if
        end if

        if r_type = 1 then
            if cur_sec = 0 then
                put  :  OutStream,  block,
counter, secname, "-Turn", bl1, " ",
                    name, bl1 + 10, "1"
            else
                put  :  OutStream,  block,
counter, secname, "-Turn", bl1, " ",
                    name, bl1 + 10, "5"
            end if
            used (bl1) := used (bl1) + 1
        elsif r_type = 2 then
            if cur_sec = 0 then
                put  :  OutStream,  block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "1"
            else
                put  :  OutStream,  block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "5"
            end if
            used (bl2) := used (bl2) + 1
        else
            if cur_sec = 0 then
                put  :  OutStream,  block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "1"
            else
                put  :  OutStream,  block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "5"
            end if
            used (bl3) := used (bl3) + 1
        end if

        if left_un = 4 then
            put : OutStream, block, counter,
"-UnblankRight ", name, "412"
            right_un := right_un + 1
        elsif right_un = 4 then
            put : OutStream, block, counter,
"-UnblankLeft ", name, "411"
            left_un := left_un + 1
        else
            if i = 1 then
                put  :  OutStream,  block,
counter, "-UnblankLeft ", name, "411"
                left_un := left_un + 1
            else
                put  :  OutStream,  block,
counter, "-UnblankRight ", name,
                    "412"
                right_un := right_un + 1
            end if
        end if

        if left_un = 4 then
            put : OutStream, block, counter,
"-UnblankRight ", name, "412"
            right_un := right_un + 1
        elsif right_un = 4 then
            put : OutStream, block, counter,
"-UnblankLeft ", name, "411"
            left_un := left_un + 1
        else
            if j = 1 then
                put  :  OutStream,  block,
counter, "-UnblankLeft ", name, "411"
                left_un := left_un + 1
            else
                put  :  OutStream,  block,
counter, "-UnblankRight ", name,
                    "412"
                right_un := right_un + 1
            end if
        end if

        put : OutStream, ""
        put : OutStream, "Exit From Cockpit
and Complete TLX"
        put : OutStream, ""
        put : OutStream, ""
    end for
    put : OutStream, ""
    put  :  OutStream,  "Refer  to  Runcodes
Sheet for Corresponding Runcodes" ..
    put "Runs Generated"
    put ""
    put left_up, " Upsets to the Left"
    put right_up, " Upsets to the Right"
    put left_un, " Left Unusual Attitudes"
    put right_un, " Right Unusual Attitudes"
    put used (1), " Turn Type 1"
    put used (2), " Turn Type 2"
    put used (3), " Turn Type 3"
    put used (4), " Turn Type 4"
    put used (5), " Turn Type 5"
    put used (6), " Turn Type 6"
    put used (7), " Turn Type 7"
    put used (8), " Turn Type 8"
    put used (9), " Turn Type 9"
    put used (10), " Turn Types 10"
    put used (11), " Turn Types 11"
    put used (12), " Turn Types 12"
    put ""
    put "VERIFY CORRECT RUNS GENERATED PRIOR
TO USE!"
elsif block = "HM" then
    for counter : 1 .. 4
        put : OutStream, "Session ", counter
        put : OutStream, ""
        if counter = 1 then
            if sectask1 = 1 then
                put  :  OutStream,  "Audio
Secondary Task"
                cur_sec := 0
            else
                put  :  OutStream,  "Visual
Secondary Task"
                cur_sec := 1
            end if
        elsif counter = 2 then
            if sectask1 = 2 then
                put  :  OutStream,  "Audio
Secondary Task"
                cur_sec := 0
            else
                put  :  OutStream,  "Visual
Secondary Task"
                cur_sec := 1
            end if
        elsif counter = 3 then
            if sectask2 = 1 then
                put  :  OutStream,  "Audio
Secondary Task"
                cur_sec := 0
            else
                put  :  OutStream,  "Visual
Secondary Task"
```

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                cur_sec := 1
            end if
        else
            if sectask2 = 2 then
                put   :   OutStream,   "Audio
Secondary Task"
                cur_sec := 0
            else
                put   :   OutStream,   "Visual
Secondary Task"
                cur_sec := 1
            end if
        end if
        put : OutStream, ""
        if cur_sec = 0 then
            secname := "Aud"
        else
            secname := "Vis"
        end if

        if cur_sec = 0 then
            put : OutStream, block, counter,
secname, "-Level ", name, "313"
        else
            put : OutStream, block, counter,
secname, "-Level ", name, "317"
        end if

        randint (bl1, 1, 4)
        randint (bl2, 5, 8)
        randint (bl3, 9, 12)
        randint (first, 1, 3)
        randint (second, 1, 2)
        randint (g, 1, 2)
        randint (h, 1, 2)
        randint (i, 1, 2)
        randint (j, 1, 2)

        passed := 0
        loop
            if used (bl1) = 1 then
                bl1 := bl1 + 1
                if bl1 = 5 then
                    bl1 := 1
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        passed := 0
        loop
            if used (bl2) = 1 then
                bl2 := bl2 + 1
                if bl2 = 9 then
                    bl2 := 5
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        passed := 0
        loop
            if used (bl3) = 1 then
                bl3 := bl3 + 1
                if bl3 = 13 then
                    bl3 := 9
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        if first = 1 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1,
                    " ", name, bl1 + 10, "3"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1,
                    " ", name, bl1 + 10, "7"
            end if
            used (bl1) := used (bl1) + 1
            if g = 1 then
                if left_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "516"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "524"
                    end if
                    right_up := right_up + 1
                elsif right_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "515"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "523"
                    end if
                    left_up := left_up + 1
                else
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "515"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "523"
                        end if
                        left_up := left_up +
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "516"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "524"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "313"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "317"
                end if
            end if
            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "3"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "7"
                end if
                used (bl2) := used (bl2) + 1
                r_type := 3
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "3"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "7"
                end if
                used (bl3) := used (bl3) + 1
                r_type := 2
            end if
        elsif first = 2 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "3"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "7"
            end if
            used (bl2) := used (bl2) + 1
            if g = 1 then
                if left_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "516"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "524"
```

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                    end if
                    right_up := right_up + 1
                elsif right_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "515"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "523"
                    end if
                    left_up := left_up + 1
                else
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "515"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "523"
                        end if
                        left_up := left_up +
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "516"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "524"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "313"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "317"
                end if
            end if

            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "3"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "7"
                end if
                used (bl1) := used (bl1) + 1
                r_type := 3
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "3"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "7"
                end if
                used (bl3) := used (bl3) + 1
                r_type := 1
            end if
        else
            if cur_sec = 0 then
                put  :  OutStream,  block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "3"
            else
                put  :  OutStream,  block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "7"
            end if
            used (bl3) := used (bl3) + 1
            if g = 1 then
                if left_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "516"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "524"
                    end if
                    right_up := right_up + 1
                elsif right_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "515"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "523"
                    end if
                    left_up := left_up + 1
                else
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "515"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "523"
                        end if
                        left_up := left_up +
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "516"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "524"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "313"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "317"
                end if
            end if

            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "3"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "7"
                end if
                used (bl1) := used (bl1) + 1
                r_type := 2
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "3"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "7"
                end if
                used (bl2) := used (bl2) + 1
                r_type := 1
            end if
        end if

        if g = 2 then
            if left_up = 2 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-UpsetRight ",
                        name, "516"
                else
                    put : OutStream, block,
counter, secname, "-UpsetRight ",
                        name, "524"
                end if
                right_up := right_up + 1
            elsif right_up = 2 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-UpsetLeft ",
                        name, "515"
                else
                    put : OutStream, block,
counter, secname, "-UpsetLeft ",
                        name, "523"
                end if
                left_up := left_up + 1
            else
                if h = 1 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "515"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "523"
                    end if
                    left_up := left_up + 1
                else
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "516"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "524"
                    end if
                    right_up := right_up + 1
                end if
            end if
        else
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Level ", name,
                    "313"
            else
                put   :   OutStream,   block,
counter, secname, "-Level ", name,
                    "317"
            end if
        end if

        if r_type = 1 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1, " ",
                    name, bl1 + 10, "3"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1, " ",
                    name, bl1 + 10, "7"
            end if
            used (bl1) := used (bl1) + 1
        elsif r_type = 2 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "3"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "7"
            end if
            used (bl2) := used (bl2) + 1
        else
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "3"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "7"
            end if
            used (bl3) := used (bl3) + 1
        end if

        if left_un = 4 then
            put : OutStream, block, counter,
"-UnblankRight ", name, "416"
            right_un := right_un + 1
        elsif right_un = 4 then
            put : OutStream, block, counter,
"-UnblankLeft ", name, "415"
            left_un := left_un + 1
        else
            if i = 1 then
                put   :   OutStream,   block,
counter, "-UnblankLeft ", name, "415"
                left_un := left_un + 1
            else
                put   :   OutStream,   block,
counter, "-UnblankRight ", name,
                    "416"
                right_un := right_un + 1
            end if
        end if

        if left_un = 4 then
            put : OutStream, block, counter,
"-UnblankRight ", name, "416"
            right_un := right_un + 1
        elsif right_un = 4 then
            put : OutStream, block, counter,
"-UnblankLeft ", name, "415"
            left_un := left_un + 1
        else
            if j = 1 then
                put   :   OutStream,   block,
counter, "-UnblankLeft ", name, "415"
                left_un := left_un + 1
            else
                put   :   OutStream,   block,
counter, "-UnblankRight ", name,
                    "416"
                right_un := right_un + 1
            end if
        end if

        put : OutStream, ""
        put : OutStream, "Exit From Cockpit
and Complete TLX"
        put : OutStream, ""
        put : OutStream, ""
    end for
    put : OutStream, ""
    put : OutStream, "Refer to Runcodes
Sheet for Corresponding Runcodes" .
    put "Runs Generated"
    put ""
    put left_up, " Upsets to the Left"
    put right_up, " Upsets to the Right"
    put left_un, " Left Unusual Attitudes"
    put right_un, " Right Unusual Attitudes"
    put used (1), " Turn Type 1"
    put used (2), " Turn Type 2"
    put used (3), " Turn Type 3"
    put used (4), " Turn Type 4"
    put used (5), " Turn Type 5"
    put used (6), " Turn Type 6"
    put used (7), " Turn Type 7"
    put used (8), " Turn Type 8"
    put used (9), " Turn Type 9"
    put used (10), " Turn Types 10"
    put used (11), " Turn Types 11"
    put used (12), " Turn Types 12"
    put ""
    put "VERIFY CORRECT RUNS GENERATED PRIOR
TO USE!"
elsif block = "FN" then
    for counter : 1 .. 4
        put : OutStream, "Session ", counter
        put : OutStream, ""
        if counter = 1 then
            if sectask1 = 1 then
                put : OutStream, "Audio
Secondary Task"
                cur_sec := 0
            else
                put : OutStream, "Visual
Secondary Task"
                cur_sec := 1
            end if
        elsif counter = 2 then
            if sectask1 = 2 then
                put : OutStream, "Audio
Secondary Task"
                cur_sec := 0
            else
                put : OutStream, "Visual
Secondary Task"
                cur_sec := 1
            end if
        elsif counter = 3 then
            if sectask2 = 1 then
                put : OutStream, "Audio
Secondary Task"
                cur_sec := 0
            else
                put : OutStream, "Visual
Secondary Task"
                cur_sec := 1
            end if
        else
            if sectask2 = 2 then
                put : OutStream, "Audio
Secondary Task"
                cur_sec := 0
            else
                put : OutStream, "Visual
Secondary Task"
                cur_sec := 1
            end if
        end if
        put : OutStream, ""
        if cur_sec = 0 then
            secname := "Aud"
        else
            secname := "Vis"
        end if

        if cur_sec = 0 then
            put : OutStream, block, counter,
secname, "-Level ", name, "312"
        else
            put : OutStream, block, counter,
secname, "-Level ", name, "316"
        end if

        randint (bl1, 1, 4)
        randint (bl2, 5, 8)
        randint (bl3, 9, 12)
        randint (first, 1, 3)
        randint (second, 1, 2)
        randint (g, 1, 2)
        randint (h, 1, 2)
        randint (i, 1, 2)
        randint (j, 1, 2)

        passed := 0
        loop
            if used (bl1) = 1 then
                bl1 := bl1 + 1
                if bl1 = 5 then
                    bl1 := 1
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        passed := 0
        loop
            if used (bl2) = 1 then
                bl2 := bl2 + 1
                if bl2 = 9 then
                    bl2 := 5
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        passed := 0
        loop
            if used (bl3) = 1 then
                bl3 := bl3 + 1
                if bl3 = 13 then
                    bl3 := 9
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        if first = 1 then
            if cur_sec = 0 then
                put : OutStream, block,
counter, secname, "-Turn", bl1,
                    " ", name, bl1 + 10, "2"
            else
                put : OutStream, block,
counter, secname, "-Turn", bl1,
                    " ", name, bl1 + 10, "6"
            end if
            used (bl1) := used (bl1) + 1
            if g = 1 then
                if left_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "514"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "522"
                    end if
                    right_up := right_up + 1
                elsif right_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "513"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "521"
                    end if
                    left_up := left_up + 1
                else
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "513"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "521"
                        end if
                        left_up := left_up +
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "514"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "522"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "312"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                         name, "316"
                end if
            end if
            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "2"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "6"
                end if
                used (bl2) := used (bl2) + 1
                r_type := 3
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "2"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "6"
                end if
                used (bl3) := used (bl3) + 1
                r_type := 2
            end if
        elsif first = 2 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "2"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "6"
            end if
            used (bl2) := used (bl2) + 1
            if g = 1 then
                if left_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "514"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "522"
                    end if
                    right_up := right_up + 1
                elsif right_up = 2 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "513"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "521"
                    end if
                    left_up := left_up + 1
                else
```

```
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "513"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "521"
                        end if
                        left_up := left_up +
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "514"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "522"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "312"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "316"
                end if
            end if

            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "2"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "6"
                end if
                used (bl1) := used (bl1) + 1
                r_type := 3
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "2"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "6"
                end if
                used (bl3) := used (bl3) + 1
                r_type := 1
            end if
        else
            if cur_sec = 0 then
                put : OutStream, block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "2"
            else
                put : OutStream, block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "6"
            end if
            used (bl3) := used (bl3) + 1
            if g = 1 then
                if left_up = 2 then
                    if cur_sec = 0 then
                        put : OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "514"
                    else
                        put : OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "522"
                    end if
                    right_up := right_up + 1
                elsif right_up = 2 then
                    if cur_sec = 0 then
                        put : OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "513"
                    else
                        put : OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "521"
                    end if
                    left_up := left_up + 1
                else
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "513"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "521"
                        end if
                        left_up := left_up +
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "514"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "522"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "312"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "316"
                end if
            end if

            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "2"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "6"
                end if
                used (bl1) := used (bl1) + 1
                r_type := 2
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "2"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "6"
                end if
                used (bl2) := used (bl2) + 1
                r_type := 1
            end if
        end if

        if q = 2 then
            if left_up = 2 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-UpsetRight ",
                        name, "514"
                else
                    put : OutStream, block,
counter, secname, "-UpsetRight ",
                        name, "522"
                end if
                right_up := right_up + 1
            elsif right_up = 2 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-UpsetLeft ",
                        name, "513"
                else
                    put : OutStream, block,
counter, secname, "-UpsetLeft ",
                        name, "521"
                end if
```

```
                left_up := left_up + 1
            else
                if h = 1 then
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "513"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "521"
                    end if
                    left_up := left_up + 1
                else
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "514"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "522"
                    end if
                    right_up := right_up + 1
                end if
            end if
        else
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Level ", name,
                    "312"
            else
                put   :   OutStream,   block,
counter, secname, "-Level ", name,
                    "316"
            end if
        end if

        if r_type = 1 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1, " ",
                    name, bl1 + 10, "2"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1, " ",
                    name, bl1 + 10, "6"
            end if
            used (bl1) := used (bl1) + 1
        elsif r_type = 2 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "2"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "6"
            end if
            used (bl2) := used (bl2) + 1
        else
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "2"
            else
```

```
                put  :  OutStream,  block,
counter, secname, "-Turn", b13, " ",
                    name, b13 + 10, "6"
            end if
            used (b13) := used (b13) + 1
        end if

        if left_un = 4 then
            put : OutStream, block, counter,
"-UnblankRight ", name, "414"
            right_un := right_un + 1
        elsif right_un = 4 then
            put : OutStream, block, counter,
"-UnblankLeft ", name, "413"
            left_un := left_un + 1
        else
            if i = 1 then
                put  :  OutStream,  block,
counter, "-UnblankLeft ", name, "413"
                left_un := left_un + 1
            else
                put  :  OutStream,  block,
counter, "-UnblankRight ", name,
                    "414"
                right_un := right_un + 1
            end if
        end if

        if left_un = 4 then
            put : OutStream, block, counter,
"-UnblankRight ", name, "414"
            right_un := right_un + 1
        elsif right_un = 4 then
            put : OutStream, block, counter,
"-UnblankLeft ", name, "413"
            left_un := left_un + 1
        else
            if j = 1 then
                put  :  OutStream,  block,
counter, "-UnblankLeft ", name, "413"
                left_un := left_un + 1
            else
                put  :  OutStream,  block,
counter, "-UnblankRight ", name,
                    "414"
                right_un := right_un + 1
            end if
        end if

        put : OutStream, ""
        put : OutStream, "Exit From Cockpit
and Complete TLX"
        put : OutStream, ""
        put   OutStream, ""
    end for
    put : OutStream, ""
    put  :  OutStream,  "Refer  to  Runcodes
Sheet for Corresponding Runcodes" ..
    put "Runs Generated"
    put ""
    put left_up, " Upsets to the Left"
    put right_up, " Upsets to the Right"
    put left_un, " Left Unusual Attitudes"
    put right_un, " Right Unusual Attitudes"
    put used (1), " Turn Type 1"
    put used (2), " Turn Type 2"
    put used (3), " Turn Type 3"
    put used (4), " Turn Type 4"
    put used (5), " Turn Type 5"
    put used (6), " Turn Type 6"
    put used (7), " Turn Type 7"
```

```
    put used (8), " Turn Type 8"
    put used (9), " Turn Type 9"
    put used (10), " Turn Types 10"
    put used (11), " Turn Types 11"
    put used (12), " Turn Types 12"
    put ""
    put "VERIFY CORRECT RUNS GENERATED PRIOR
TO USE!"
else
    for counter : 1 .. 4
        put : OutStream, "Session ", counter
        put : OutStream, ""
        if counter = 1 then
            if sectask1 = 1 then
                put  :  OutStream,  "Audio
Secondary Task"
                cur_sec := 0
            else
                put      OutStream,  "Visual
Secondary Task"
                cur_sec := 1
            end if
        elsif counter = 2 then
            if sectask1 = 2 then
                put  :  OutStream,  "Audio
Secondary Task"
                cur_sec := 0
            else
                put  :  OutStream,  "Visual
Secondary Task"
                cur_sec := 1
            end if
        elsif counter = 3 then
            if sectask2 = 1 then
                put  :  OutStream,  "Audio
Secondary Task"
                cur_sec := 0
            else
                put  :  OutStream,  "Visual
Secondary Task"
                cur_sec := 1
            end if
        else
            if sectask2 = 2 then
                put  :  OutStream,  "Audio
Secondary Task"
                cur_sec := 0
            else
                put  :  OutStream,  "Visual
Secondary Task"
                cur_sec := 1
            end if
        end if
        put : OutStream, ""
        if cur_sec = 0 then
            secname := "Aud"
        else
            secname := "Vis"
        end if

        if cur_sec = 0 then
            put : OutStream, block, counter,
secname, "-Level ", name, "314"
        else
            put : OutStream, block, counter,
secname, "-Level ", name, "318"
        end if

        randint (b11, 1, 4)
        randint (b12, 5, 8)
        randint (b13, 9, 12)
        randint (first, 1, 3)
        randint (second, 1, 2)
        randint (g, 1, 2)
        randint (h, 1, 2)
        randint (i, 1, 2)
        randint (j, 1, 2)

        passed := 0
        loop
            if used (bl1) = 1 then
                bl1 := bl1 + 1
                if bl1 = 5 then
                    bl1 := 1
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        passed := 0
        loop
            if used (bl2) = 1 then
                bl2 := bl2 + 1
                if bl2 = 9 then
                    bl2 := 5
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        passed := 0
        loop
            if used (bl3) = 1 then
                bl3 := bl3 + 1
                if bl3 = 13 then
                    bl3 := 9
                end if
            else
                passed := 1
            end if
            exit when passed = 1
        end loop

        if first = 1 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1,
                    " ", name, bl1 + 10, "4"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1,
                    " ", name, bl1 + 10, "8"
            end if
            used (bl1) := used (bl1) + 1
            if g = 1 then
                if left_up = 2 then
                    if cur_sec = 0 then
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "518"
                    else
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "526"
                    end if
                    right_up := right_up + 1
```

```
                elsif right_up = 2 then
                    if cur_sec = 0 then
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "517"
                    else
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "525"
                    end if
                    left_up := left_up + 1
                else
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "517"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "525"
                        end if
                        left_up := left_up +
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "518"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "526"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "314"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "318"
                end if
            end if
            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "4"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl2,
                        " ",
                        name, bl2 + 10, "8"
                end if
                used (bl2) := used (bl2) + 1
                r_type := 3
            else
                if cur_sec = 0 then
                    put    OutStream, block,
counter, secname, "-Turn", bl3.
                        " ",
                        name, bl3 + 10, "4"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "8"
                end if
                used (bl3) := used (bl3) + 1
                r_type := 2
            end if
        elsif first = 2 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "4"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 - 10, "8"
            end if
            used (bl2) := used (bl2) + 1
            if g = 1 then
                if left_up = 2 then
                    if cur_sec = 0 then
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "518"
                    else
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "526"
                    end if
                    right_up := right_up + 1
                elsif right_up = 2 then
                    if cur_sec = 0 then
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "517"
                    else
                        put    :    OutStream,
block, counter, secname,
                            "-UpsetLeft ",
                            name, "525"
                    end if
                    left_up := left_up + 1
                else
                    if h = 1 then
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "517"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetLeft
",
                                name, "525"
                        end if
```

```
                        left_up := left_up -
1
                    else
                        if cur_sec = 0 then
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "518"
                        else
                            put : OutStream,
block, counter, secname,
                                "-UpsetRight
",
                                name, "526"
                        end if
                        right_up := right_up
+ 1
                    end if
                end if
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "314"
                else
                    put : OutStream, block,
counter, secname, "-Level ",
                        name, "318"
                end if
            end if

            if second = 1 then
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "4"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl1,
                        " ",
                        name, bl1 + 10, "8"
                end if
                used (bl1) := used (bl1) + 1
                r_type := 3
            else
                if cur_sec = 0 then
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "4"
                else
                    put : OutStream, block,
counter, secname, "-Turn", bl3,
                        " ",
                        name, bl3 + 10, "8"
                end if
                used (bl3) := used (bl3) + 1
                r_type := 1
            end if
        else
            if cur_sec = 0 then
                put       OutStream,    block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "4"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "8"
            end if
```

```
             used (b13) := used (b13) + 1
             if g = 1 then
                 if left_up = 2 then
                     if cur_sec = 0 then
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetRight ",
                             name, "518"
                     else
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetRight ",
                             name, "526"
                     end if
                     right_up := right_up + 1
                 elsif right_up = 2 then
                     if cur_sec = 0 then
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetLeft ",
                             name, "517"
                     else
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetLeft ",
                             name, "525"
                     end if
                     left_up := left_up + 1
                 else
                     if h = 1 then
                         if cur_sec = 0 then
                             put : OutStream,
block, counter, secname,
                                 "-UpsetLeft
",

                                 name, "517"
                         else
                             put : OutStream,
block, counter, secname,
                                 "-UpsetLeft
",

                                 name, "525"
                         end if
                         left_up := left_up +
1

                     else
                         if cur_sec = 0 then
                             put : OutStream,
block, counter, secname,
                                 "-UpsetRight
",

                                 name, "518"
                         else
                             put : OutStream,
block, counter, secname,
                                 "-UpsetRight
",

                                 name, "526"
                         end if
                         right_up := right_up
+ 1

                       end if
                 end if
            else
                 if cur_sec = 0 then
                     put : OutStream, block,
counter, secname, "-Level ",
                         name, "314"
                 else
                     put : OutStream, block,
counter, secname, "-Level ",
```

```
                          name, "318"
                 end if
             end if

             if second = 1 then
                 if cur_sec = 0 then
                     put : OutStream, block,
counter, secname, "-Turn", bl1,
                          " ",
                          name, bl1 + 10, "4"
                 else
                     put : OutStream, block,
counter, secname, "-Turn", bl1,
                          " ",
                          name, bl1 + 10, "8"
                 end if
                 used (bl1) := used (bl1) + 1
                 r_type := 2
             else
                 if cur_sec = 0 then
                     put : OutStream, block,
counter, secname, "-Turn", bl2,
                          " ",
                          name, bl2 + 10, "4"
                 else
                     put : OutStream, block,
counter, secname, "-Turn", bl2,
                          " ",
                          name, bl2 + 10, "8"
                 end if
                 used (bl2) := used (bl2) + 1
                 r_type := 1
             end if
         end if

         if g = 2 then
             if left_up = 2 then
                 if cur_sec = 0 then
                     put : OutStream, block,
counter, secname, "-UpsetRight ",
                         name, "518"
                 else
                     put : OutStream, block,
counter, secname, "-UpsetRight ",
                         name, "526"
                 end if
                 right_up := right_up + 1
             elsif right_up = 2 then
                 if cur_sec = 0 then
                     put : OutStream, block,
counter, secname, "-UpsetLeft ",
                         name, "517"
                 else
                     put : OutStream, block,
counter, secname, "-UpsetLeft ",
                         name, "525"
                 end if
                 left_up := left_up + 1
            else
                 if h = 1 then
                     if cur_sec = 0 then
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetLeft ",
                             name, "517"
                     else
                         put   :   OutStream,
block, counter, secname,
                             "-UpsetLeft ",
                             name, "525"
                     end if
```

```
                    left_up := left_up + 1
                else
                    if cur_sec = 0 then
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "518"
                    else
                        put   :   OutStream,
block, counter, secname,
                            "-UpsetRight ",
                            name, "526"
                    end if
                    right_up := right_up + 1
                end if
            end if
        else
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Level ", name,
                    "314"
            else
                put   :   OutStream,   block,
counter, secname, "-Level ", name,
                    "318"
            end if
        end if

        if r_type = 1 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1, " ",
                    name, bl1 + 10, "4"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl1, " ",
                    name, bl1 + 10, "8"
            end if
            used (bl1) := used (bl1) + 1
        elsif r_type = 2 then
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "4"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl2, " ",
                    name, bl2 + 10, "8"
            end if
            used (bl2) := used (bl2) + 1
        else
            if cur_sec = 0 then
                put   :   OutStream,   block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "4"
            else
                put   :   OutStream,   block,
counter, secname, "-Turn", bl3, " ",
                    name, bl3 + 10, "8"
            end if
            used (bl3) := used (bl3) + 1
        end if

        if left_un = 4 then
            put : OutStream, block, counter,
"-UnblankRight ", name, "418"
            right_un := right_un + 1
        elsif right_un = 4 then
            put : OutStream, block, counter,
"-UnblankLeft ", name, "417"
            left_un := left_un + 1
        else
            if i = 1 then
                put      OutStream,   block,
counter, "-UnblankLeft ", name, "417"
                left_un := left_un + 1
            else
                put   :   OutStream,   block,
counter, "-UnblankRight ", name,
                    "418"
                right_un := right_un + 1
            end if
        end if

        if left_un = 4 then
            put : OutStream, block, counter,
"-UnblankRight ", name, "418"
            right_un := right_un + 1
        elsif right_un = 4 then
            put : OutStream, block, counter,
"-UnblankLeft ", name, "417"
            left_un := left_un + 1
        else
            if j = 1 then
                put   :   OutStream,   block,
counter, "-UnblankLeft ", name, "417"
                left_un := left_un + 1
            else
                put   :   OutStream,   block,
counter, "-UnblankRight ", name,
                    "418"
                right_un := right_un + 1
            end if
        end if

        put : OutStream, ""
        put : OutStream, "Exit From Cockpit
and Complete TLX"
        put : OutStream, ""
        put : OutStream, ""
    end for
    put : OutStream, ""
    put  :  OutStream,  "Refer  to  Runcodes
Sheet for Corresponding Runcodes" ..
    put "Runs Generated"
    put ""
    put left_up, " Upsets to the Left"
    put right_up, " Upsets to the Right"
    put left_un, " Left Unusual Attitudes"
    put right_un, " Right Unusual Attitudes"
    put used (1), " Turn Type 1"
    put used (2), " Turn Type 2"
    put used (3), " Turn Type 3"
    put used (4), " Turn Type 4"
    put used (5), " Turn Type 5"
    put used (6), " Turn Type 6"
    put used (7), " Turn Type 7"
    put used (8), " Turn Type 8"
    put used (9), " Turn Type 9"
    put used (10), " Turn Types 10"
    put used (11), " Turn Types 11"
    put used (12), " Turn Types 12"
    put ""
    put "VERIFY CORRECT RUNS GENERATED PRIOR
TO USE!"
end if
```

Appendix C

Pilot Briefing Documents

UTIAS Flight Simulation Laboratory

Attitude Director Indicator Experiment
Pilot Briefing Document

January 2001

Background

Introduction

While many additional navigation instruments and displays have been developed, the ADI remains an important instrument in modern cockpits. In most cases, the ADI acts as the primary flight display under instrument flight. The ADI itself has changed with the introduction of "glass cockpits" which allow the display to be presented using colour graphics and computer generated symbology, but the information conveyed and the format in general use remains essentially unchanged.

Experiment Objective

This experiment is primarily a study of pilot performance while using two different types of ADI displays. To avoid bias, test subjects will only be introduced to one ADI display at a time. The performance and work load while using the two different ADI's while conducting various flight tasks will be measured. Test subjects will also be asked to give their subjective evaluations.

In addition, the effects of simulator motion on pilot performance will also be evaluated in this experiment. To this end, all flight tasks will be performed using the flight simulator with both motion cues switched on and off.

The Flight Simulator

The UTIAS Flight Research Simulator consists of a general aircraft cab mounted on a 6 degrees-of-freedom motion base manufactured by CAE (see Figure 1). This experiment will make use of the rear-facing station in the cab, with out-the-window scenery generated by a CAE MaxVue visual system and the electronic flight instrument system (EFIS) displayed on a separate 19-inch colour display monitor.

The aircraft will be controlled using a control stick with the right arm. The left hand will be used to control a small joystick for secondary tasks.

The Aircraft

In this experiment, the flight simulator will be set up to simulate the behaviour of a T-33 jet aircraft (see Figure 2). The T-33 was the world's first jet trainer, and was developed from the single-seat F-80 fighter. The T-33 entered service with the United States Air Force in 1948, and was eventually exported to be used by the navies and air forces of more than 20 countries.

The T-33 jet trainer measures a span of 38 feet 10 ½ inches, a length of 37 feet 9 inches, and weighs 12000 lbs. The powerplant is a single Allison J33-A-23 turbojet of 5200 lbs of thrust. Maximum speed is 525 mph, and ceiling is 47500 feet.

Experimental Organization

Each subject will be assigned a starting block, which will determine the order in which the various different simulator configurations are introduced. These various simulator configurations will expose the subjects to two different types of ADI's, and use of the simulator either with or without motion cues.

Cockpit Controls and Displays

To simplify the flying task and minimize training time, subjects will only be required to control the aircraft in roll. Pitch and thrust will be controlled by the aircraft autopilot in order to maintain a constant airspeed and altitude.

Roll is controlled by moving the primary control stick to the left or right. The stick is controlled using the right arm. There will be no need to trim the stick, and none of the buttons should be used except the emergency stop button if required (refer to Safety Procedures). The control stick will not function in pitch as that is controlled by the autopilot. Similarly, the rudder pedals will be non-functional for this experiment.

The left hand will be used to control a small joystick similarly to ones used for computer games. This stick will only be used in the fore/aft direction for secondary task control. Note that this stick has trim tabs which should not be altered during the course of the experiment. If the trim is accidentally shifted, the experimenter should be notified immediately.

The cockpit instrumentation is displayed on a 19-inch colour CRT. This Electronic Flight Instrument System (EFIS) presents a large amount of information useful for flight. In this experiment, the most important instruments will be the compass and the ADI. The functions of the EFIS display will be thoroughly explained and demonstrated during training.

Secondary Tasks

In order to assess the level of pilot workload, all subjects will be required to perform a secondary task while flying the simulator. Two secondary tasks will be used in this experiment, the audio tracking task, and the visual tracking task. Prior to beginning simulator training, all subjects will practice performing the secondary tasks alone without attending to flying.

Both the audio and visual tracking tasks involve the use of a joystick controller to maintain a signal at a desired level. As the signal drifts away from the desired level pilot inputs are used to cancel the drift. In the audio task, the signal is an audio tone that must be maintained at the desired frequency (or pitch). Pushing forward on the joystick raises the frequency, and pulling back on the joystick lowers the frequency.

For the visual task, a bar graph display will be used where the bar will rise towards the top or drop towards the bottom, the goal being to maintain the bar in the middle of the column. The polarity of the joystick in this case is set to mimic an aircraft control stick. In other words, pushing forward on the joystick causes the bar to fall, and pulling back raises the bar.

Tips for Secondary Tasks

1. For the audio task, a reference tone will be given once every ten seconds. Constant "humming" of the note may help in keeping track of the desired frequency.
2. Use a gentle touch on the joystick. The goal is to softly "nudge" the signal in the desired direction. Large joystick movements will cause constant overshoot, resulting in increased work and poor tracking performance.
3. Always remember that the flight task is primary. At critical moments, performance in the secondary task should be compromised for maximum performance in the primary flight task. However, the secondary task should not be entirely abandoned.
4. There are "hard-limits" on the secondary tasks that prevent drifting too far off the desired signal level. Once the upper or lower limits are hit, the signal will

not drift any further. However, recovery from the limits can be tricky as the tendency is to use maximum input on the joystick, but this will most probably cause overshoot. Try to use gentle smooth inputs.

5. Discover the individual technique that works best for you during the practice run sessions. The secondary task should feel natural for best performance.

Simulator Flight Training

All subjects will begin training by flying in visual flight conditions (out-the-window view active), no ADI display, and no motion. The first task will be to learn to maintain straight and level flight by use of the control stick. After this, turning the aircraft in free flight will be practiced. The emphasis is to fly the simulator like a pilot would a real aircraft. That is, stick inputs are smooth and controlled, rather than abrupt and rough as one might have in an arcade game.

When the subject can turn the aircraft with sufficient skill, the experimenter will then lead the subject through a series of commanded heading changes at specified bank angles. Use of the compass will be essential for this task. In addition, since the ADI is not active, the experimenter will guide the subjects to the proper bank angle. The purpose of this is to acquire a feel to the inputs necessary to bring the aircraft to certain bank angles.

Finally, the subjects will be asked to complete a demanding flying task which will involve controlling the aircraft while attending to a secondary task. In the simulator your primary task is flying the aircraft. You should do this to the best of your ability. As time permits, you should attend to the secondary task. However, the secondary task should not be ignored as it represents an important part of the pilot's cockpit workload.

Flight Test Routine

After the subject has mastered the general operation of the simulator, one of the two ADI's will be introduced. Its operation will be explained and demonstrated, and then a series of flight test sessions will begin. Each session will consists of four main tasks: level tracking, heading change, sudden attitude upset recovery, and unusual attitude recovery. These tasks will be explained in detail below.

Level Tracking and Heading Change

The experiment will begin with the aircraft flying straight and level through turbulent air. Since the aircraft will roll randomly, the pilot must use the flight control to maintain straight and level.

On heading change runs, heading change commands will be issued at certain times. The experimenter will state the direction of turn, the new desired heading, and the bank angle desired while turning to the new heading. For example, the experimenter may say, "Turn left to a heading of three-three-zero with 30 degrees bank." Assume that the aircraft was flying north (heading zero-zero-zero) at the time. The desired action would be to turn left until the aircraft is banked at 30 degrees, and maintain the bank angle until just before the heading has reached 330. The command will be given slightly in advance, and the turn should commence once the experimenter has given the command, "Turn now."

Sudden Attitude Upset

The Sudden Attitude Upset will simulate a wake vortex encounter. An encounter with the trailing wake vortex of a preceding aircraft is a potentially dangerous situation, and has been identified as the cause of a number of fatal accidents involving both civil aircraft and jetliners. This sudden upset of aircraft attitude may lead to pilot confusion and disorientation, making it ideal for testing performance of attitude indicator displays.

In this experiment, you will experience random occurrences of wake vortex encounters. The effect on the aircraft will be a sudden roll in one direction. You should try to counteract the roll using the flight controls in a timely manner to minimize the roll disturbance.

Unusual Attitude Recovery

The unusual attitude recovery is designed to simulate a situation in which the aircraft has drifted to an orientation away from straight and level. If the movement is gradual and below the human vestibular threshold the pilot may be unaware of the drift and consequently will be surprised to find the aircraft in an unexpected attitude.

To create this situation in the simulator, the cockpit display instrumentation will be temporarily blanked while the aircraft is gradually banked. The displays will then be switched on, at which time the pilot is expected to judge the aircraft's attitude from the ADI, and use the flight controls to return the aircraft to straight and level in a timely manner.

The subjects will not be required to perform secondary tasks for this flight task.

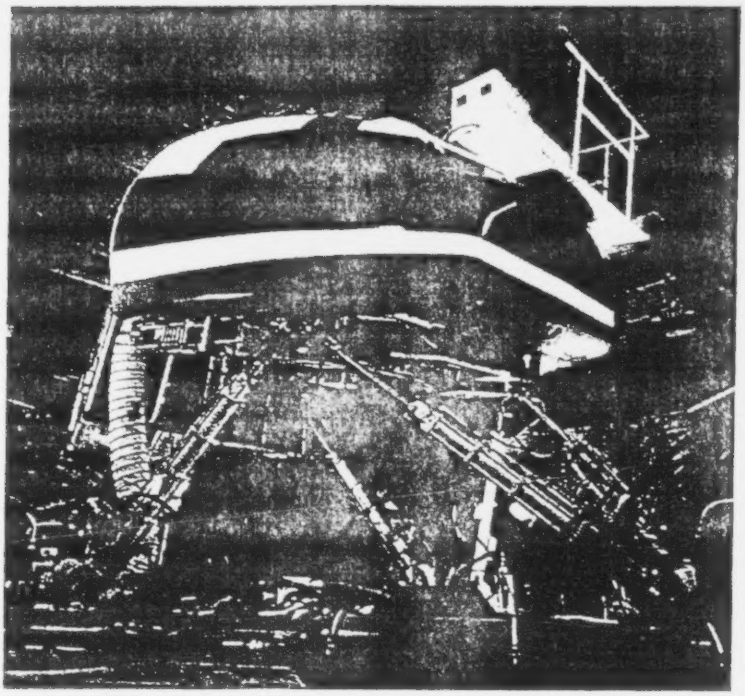


Figure 1 – The UTIAS Flight Research Simulator

U.S. AIR FORCE

Figure 2 – The T-33 Jet

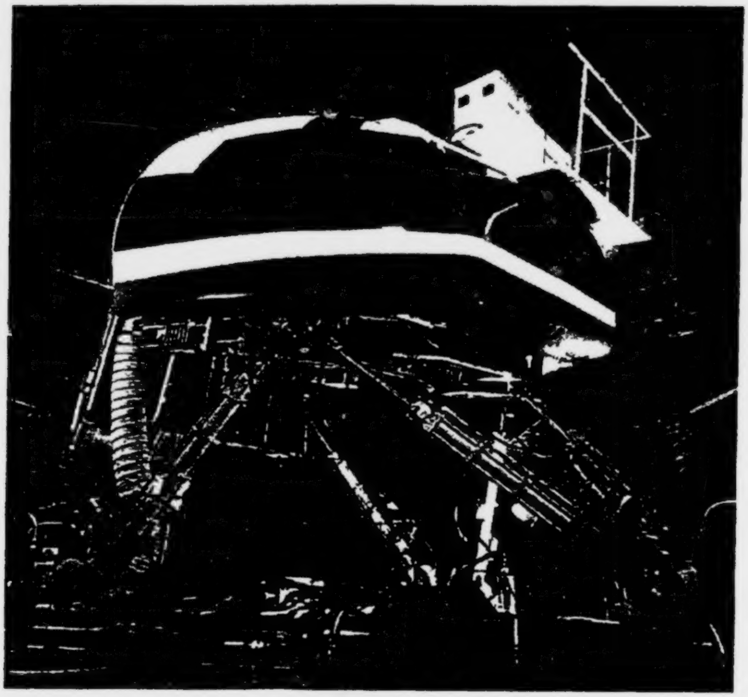


Figure 1 – The UTIAS Flight Research Simulator

U.S. AIR FORCE

Figure 2 – The T-33 Jet

Post-Session Ratings

SUBJECT INSTRUCTIONS: RATINGS

We are not only interested in assessing your performance but also the experiences you had during the different task conditions. Right now we are going to describe the technique that will be used to examine your experiences. In the most general sense we are examining the "Workload" you experienced. Workload is a difficult concept to define precisely, but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put in, or the stress and frustration you felt. The workload contributed by different task elements may change as you get more familiar with a task, perform easier or harder versions of it, or move from one task to another. Physical components of workload are relatively easy to conceptualize and evaluate. However, the mental components of workload may be more difficult to measure.

Since workload is something that is experienced individually by each person, there are no effective "rulers" that can be used to estimate the workload of different activities. One way to find out about workload is to ask people to describe the feelings they experienced. Because workload may be caused by many different factors, we would like you to evaluate several of them individually rather than lumping them into a single global evaluation of overall workload. Attached to this document you will find a set of nine rating scales that were developed for you to use in evaluating your experiences during different tasks. Each is accompanied by a detailed description to help you gauge its meaning – please read these carefully. If you have a question about any of the scales, please ask about it. It is extremely important that they be clear to you.

After performing the task, you will be seated at a computer that will display each of the nine rating scales and their descriptions one at a time. You will evaluate the task by marking each scale at the point which matches your experience. Each line has two endpoint descriptors that describe the scale. Note that "Performance" goes from "good" on the left to "bad" on the right. This order has been confusing for some people. Drag the slider bar marker from its position at the left of the scale to the right until it points at the desired location. When you are satisfied with your choice, press the **Next** button at the lower left of the display, and the next rating scale will appear.

Please consider your responses carefully in distinguishing among the task conditions. Consider each scale individually. Your ratings will play an important role in the evaluation being conducted, thus, your active participation is essential to the success of this experiment, and is greatly appreciated.

SUBJECT INSTRUCTIONS: SOURCES-OF-WORKLOAD

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended or the performance they achieved. Others feel that if they performed well the workload must have been low, and vice versa. Yet others feel that effort or feelings of frustration are the most important factors in workload, and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

After each set of tasks, you will complete an evaluation that has been developed by NASA to assess the relative importance of six particular factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to your experience of workload in the task(s) that you just performed. Each pair of scale titles will appear separately on the screen. Select- the rating scale title that represents the more important contributor to workload- for the specific task(s) you performed in this experiment.

Position the mouse pointer (arrow) over the large button labeled with the rating scale title that you feel is the most important of the two. Click down on the left mouse button to select this rating scale. If you wish to change your mind, simply click the other button. When you are satisfied with your choice, press the **Next** button at the lower left of the display, and a new pair of rating scale titles will appear.

After you have finished the entire series we will be able to use the pattern of your choices to create a weighted combination of the ratings from that task into a summary workload score. Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any *correct* pattern; we are only interested in your opinions. If you have any questions, please ask them before the evaluation is performed. Thank you for your participation.

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

VISUAL DEMAND	*Low/High*	How much effort did you have to put into gathering all of the visual information required for the task? Did it require casual glances, with easily read instruments and low priority monitoring, or continuous searching, with hard to read instruments and poor visibility?
AUDITORY DEMAND	*Low/High*	How much attention did you have to put into listening for relevant information during the task? Was there little important talk, with low ambient noise and few distracting sounds, or intense discussion, a noisy environment, and important ambient sounds and alarms?
GLOBAL WORKLOAD	*Low/High*	Considering all aspects, how would you rate the demands of the task? Was it easy and automatic, with little attention or thought required, or difficult and overwhelming, requiring full concentration and resulting in lots of errors?

University of Toronto Institute for Aerospace Studies
Flight Research Simulator Facility

Simulator Safety Procedures

The simulator hardware and software have been designed to work safely and reliably. To ensure your safety, please observe the following rules:

1. *Always use the four-strap harness Remain seated and strapped-in at all times while in the simulator.*
2. *When the experimental run is over, remain seated and strapped-in until the lights come on and the experimenter tells you that you may release the harness.*
3. *In any event, if the gangway leading to the simulator has been raised, do not open the door until the gangway has reached the DOWN position and shut itself off as indicated by the blue light beside the door.*
4. *The experimenter is always in contact via the intercom. Contact him/her if you need instructions or advice.*
5. *At any time during a run, you can shut down the motion system and the control loader by pressing the large red 'panic' button (front right wall) or the upper red thumb button (to the left of the top 4-way trim switch) on the flight control stick.*

In the unlikely event of an emergency such as fire, there are a number of features built into the simulator which allow you to exit quickly and safely. Follow these steps:

1. *Tell the experimenter what is wrong. If the motion base is engaged, press one of the emergency buttons to shut it down as described above.*
2. *Remained seated and strapped in until the motion base has stopped moving and the experimenter tells you what to do. If the intercom fails, remain seated until the motion base has stopped and proceed as outlined below.*
3. *If there is no immediate danger, ensure that the gangway is lowered and exit on it. If, however, you need to exit immediately, open the door and climb down the rope stowed above the door.*
4. *If the exit door will not open, then open the exit hatch in the door and climb down using the rope stowed above the door*
5. *In the case of fire, your first priority should be to get out of the cab safely. If the fire is small and exposed, you may use the fire extinguisher located to the right of the front right-hand pilot seat*

If the lights remain out, use the small flashlight located on the lower left side of the rear window box.

University of Toronto Institute for Aerospace Studies
Flight Research Simulator Facility

Subject Consent Form

I, the undersigned, hereby agree to participate as a test subject in the study entitled ADI Experiment. I acknowledge that I have read and understood the protocol describing the experiment, that I have had the opportunity to ask any questions I may have and that all questions have been answered to my satisfaction.

I understand that my participation in the experiment will involve operations inside the UTIAS Flight Research Simulator, and I acknowledge that I have read and understood the simulator safety procedures.

I understand that I am free to withdraw from this experiment at any time without prejudice, that the investigator may terminate the experiment at any time without my consent, and that all data gathered will be kept in confidence.

Date: ____

Subject Name (please print): ____________________________

Subject Signature: ____________________________________

Witness Name (please print): ___________________________

Witness Signature: ____________________________________

Appendix D

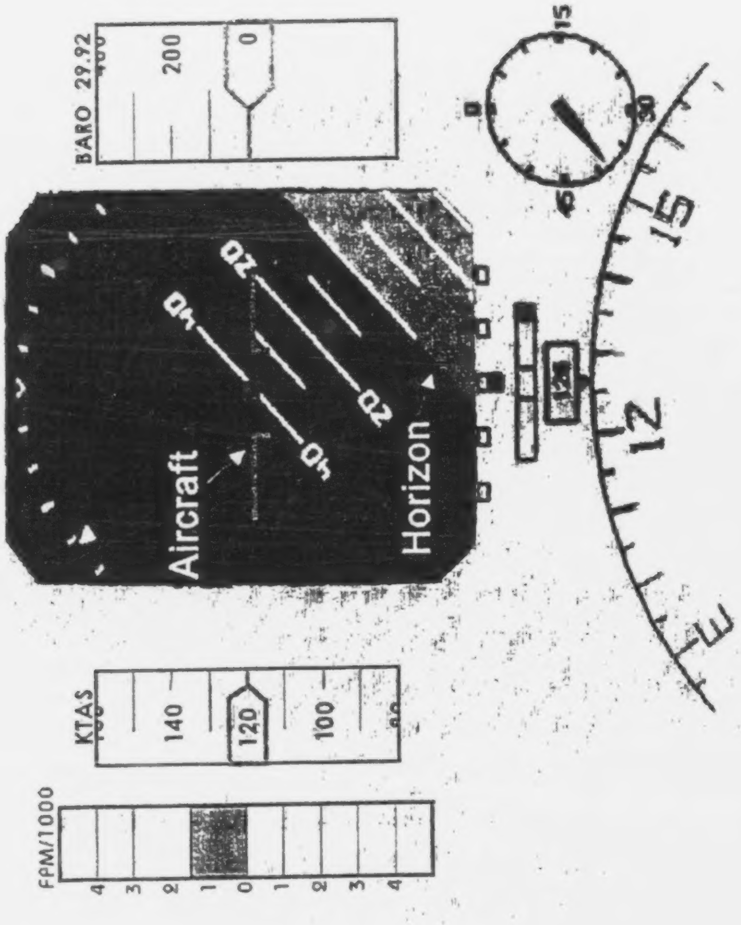
ADI Briefing Notes

Moving Horizon Display Briefing Notes

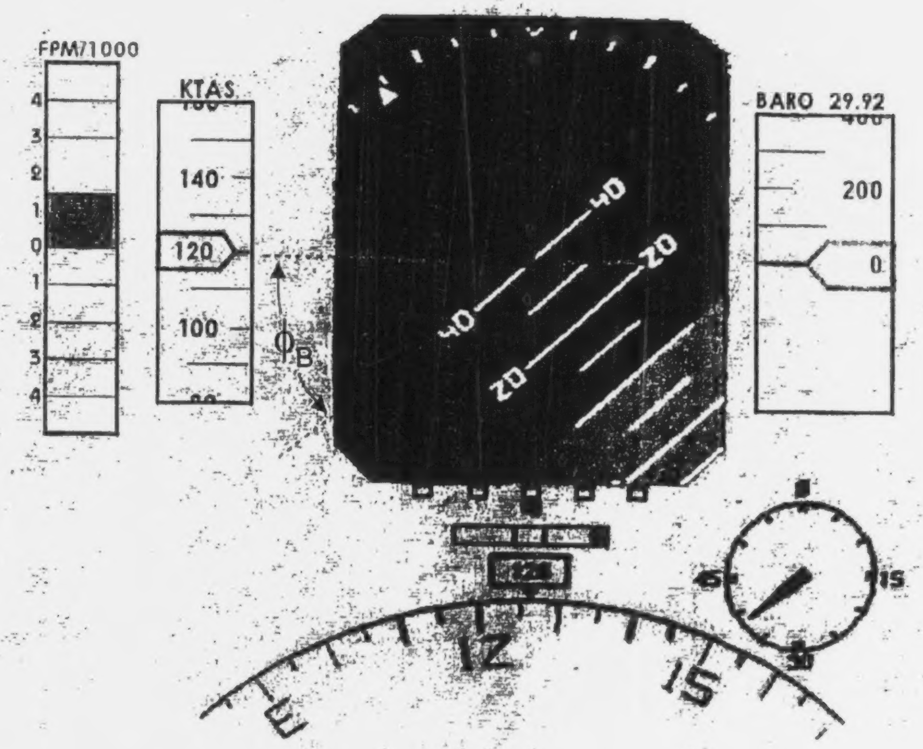
- This display has two symbols: the aircraft symbol, and the artificial horizon
- It also has bank angle indicators, and pitch lines
- The aircraft symbol is stationary on the screen, it is fixed to the actual aircraft you are flying
- The artificial horizon moves to show how the real horizon would appear when you look outside the window in visual conditions
- The angle between the aircraft symbol and the artificial horizon is always the actual bank angle between the real aircraft and the ground

Frequency Separated Display Briefing Notes

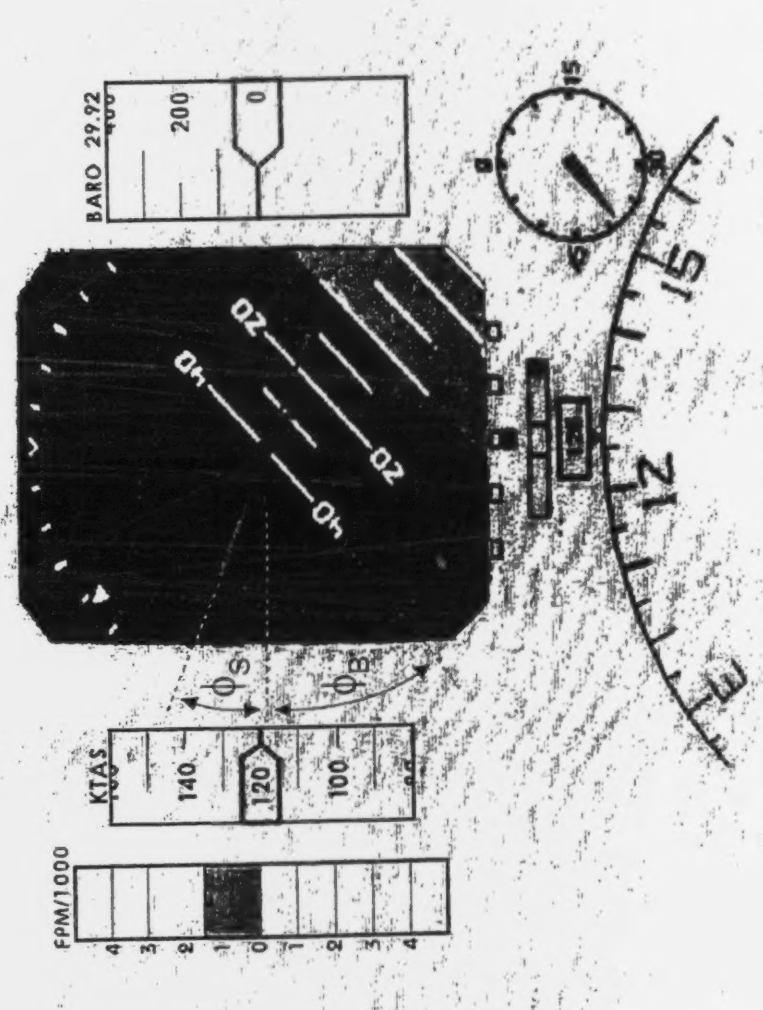
- This display has two symbols: the aircraft symbol, and the artificial horizon
- It also has bank angle indicators, and pitch lines
- The artificial horizon banks to show how the real horizon would appear when you look outside the window in visual conditions
- The aircraft symbol will move to indicate the deflection of the ailerons (the lateral displacement of the control stick)
- The direction the aircraft symbol rolls is the direction the actual aircraft will roll under the applied aileron input
- When there is no aileron deflection, the aircraft symbol sits horizontally; only in this case does the angle between the aircraft symbol and the artificial horizon indicate the actual bank angle of the aircraft relative to the Earth
- Maintaining the aircraft symbol parallel to the artificial horizon line will always return the aircraft to straight and level


BARO 29.92
200
0
Aircraft
Horizon
10
20
KTAS
140
120
100
FPM/1000
4
3
2
1
0
1
2
3
4
15
12
E
0
15
30
45

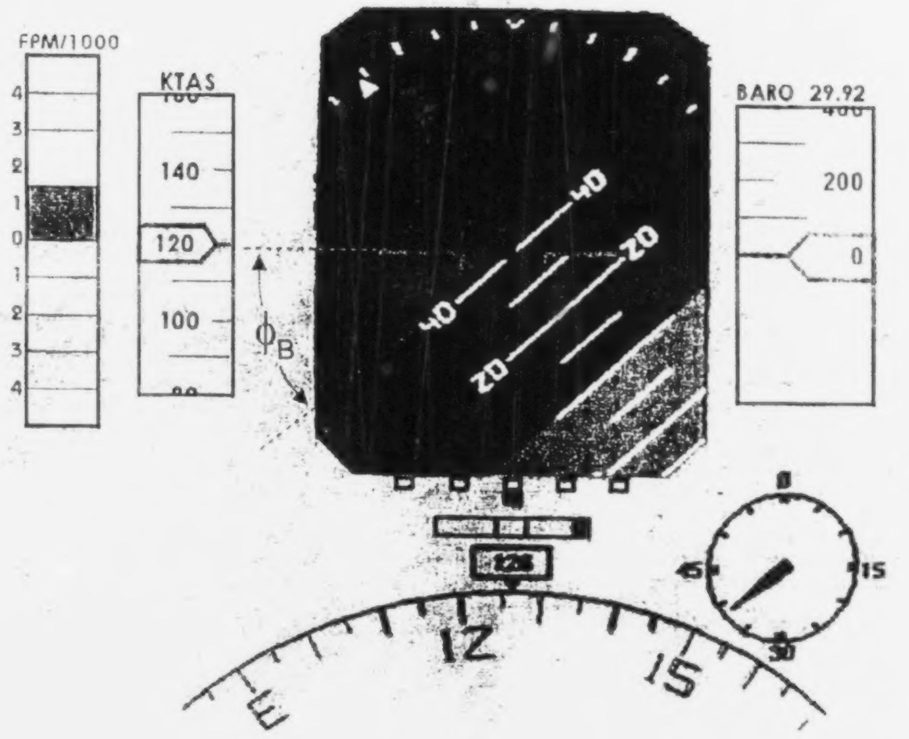
ADI Symbology


FPM/1000
4
3
2
1
0
1
2
3
4
KTAS
140
120
100
Φ_B
40
20
20
40
BARO 29.92
200
0
E
12
15
15
30
45

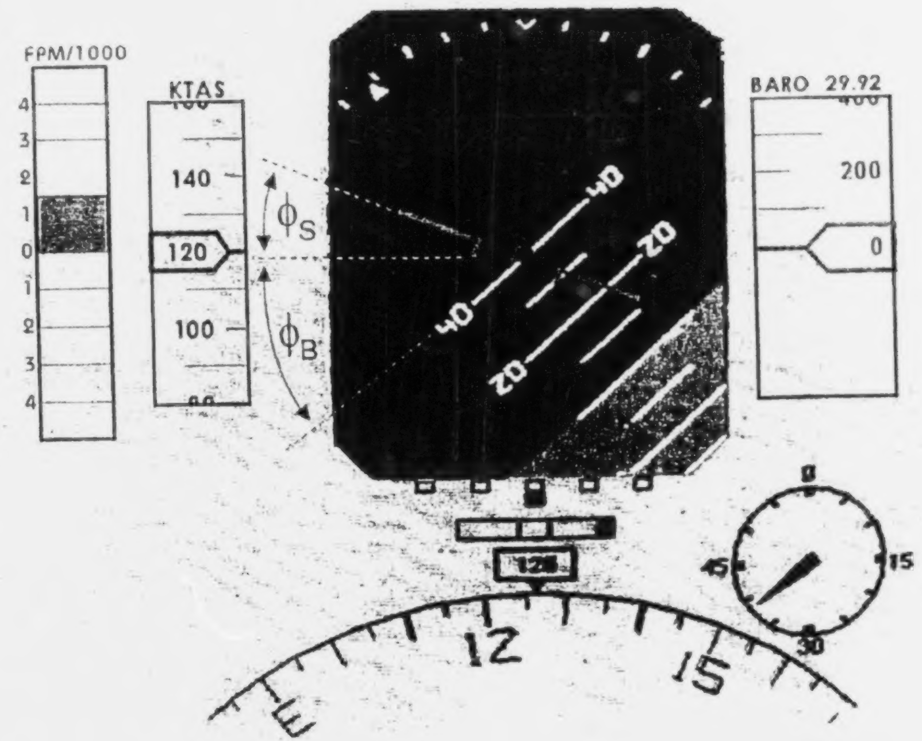
Moving Horizon ADI


BARO 29.92
400
200
0
KTAS
160
140
120
100
80
FPM/1000
4
3
2
1
0
1
2
3
4
20
40
20
40
ϕ_S
ϕ_B
E
12
15
15

Frequency Separated ADI

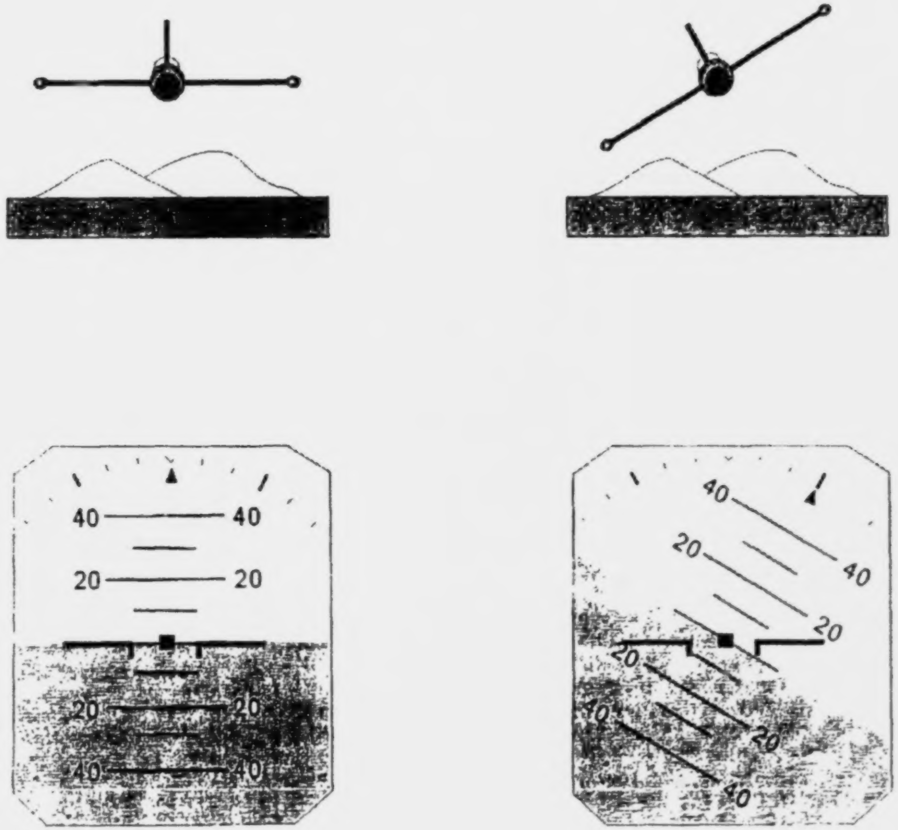

FPM/1000
4
3
2
1
0
1
2
3
4
KTAS
140
120
100
40
20
20
40
ϕ_B
BARO 29.92
200
0
0
15
45
30
12
15
E

Moving Horizon ADI


FPM/1000
4
3
2
1
0
1
2
3
4
KTAS
140
120
100
ϕ_S
ϕ_B
40
20
20
40
BARO 29.92
200
0
128
0
15
30
45
12
15
E

Frequency Separated ADI

Moving Horizon ADI Display


40
40
20
20
20
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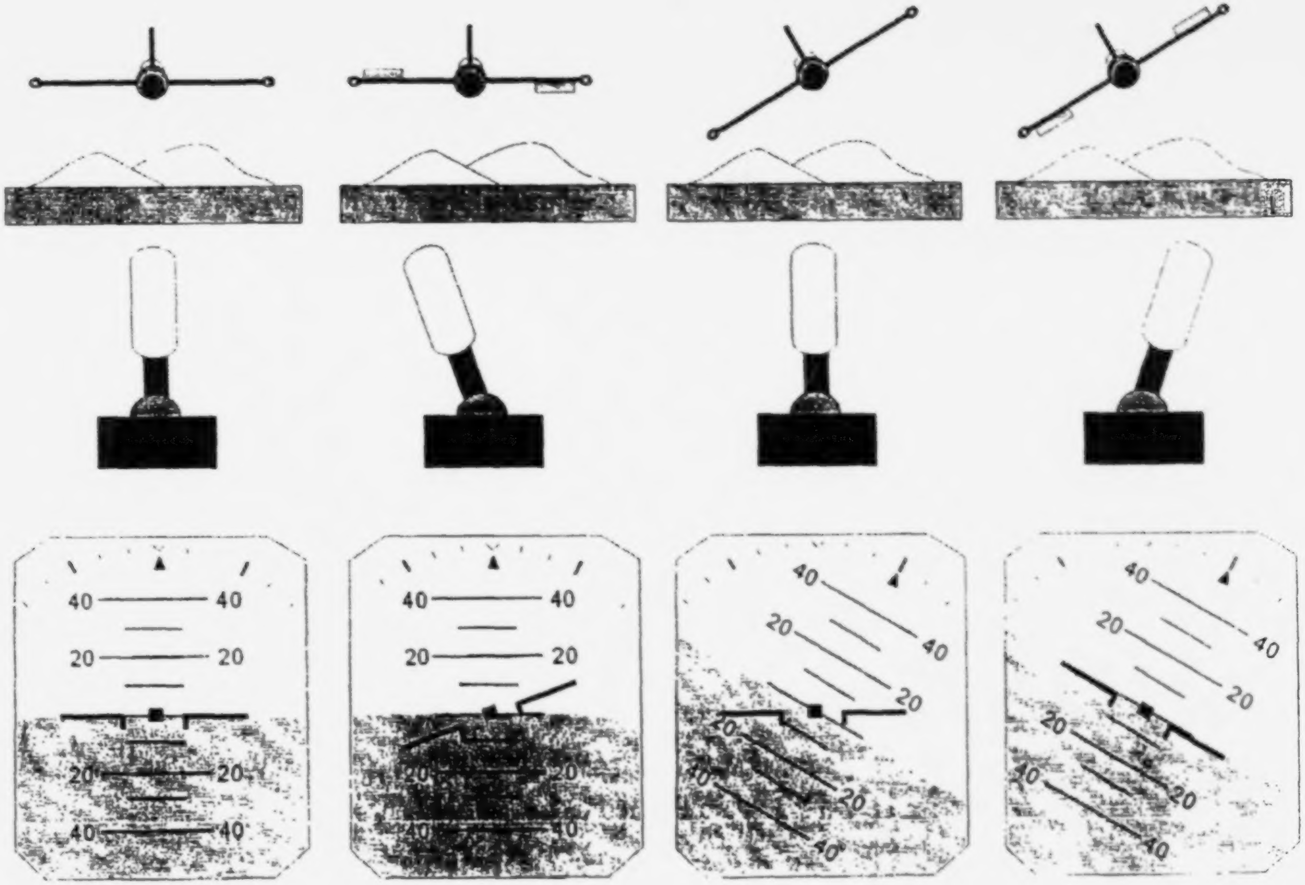
20
20
40

Frequency Separated ADI Display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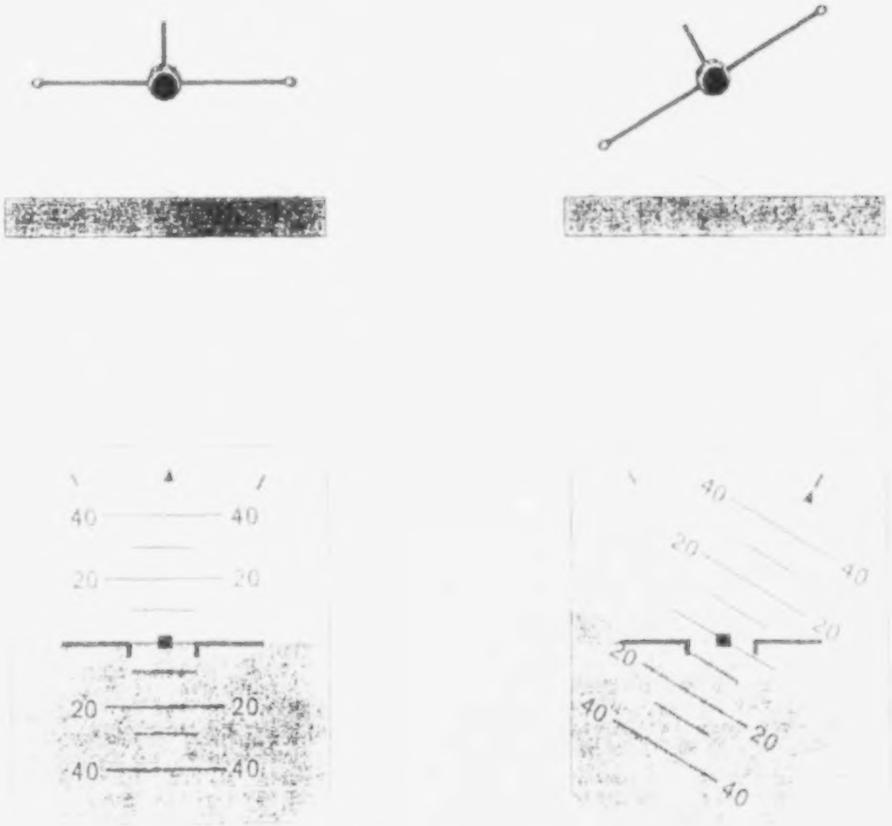
40

Moving Horizon ADI Display


40
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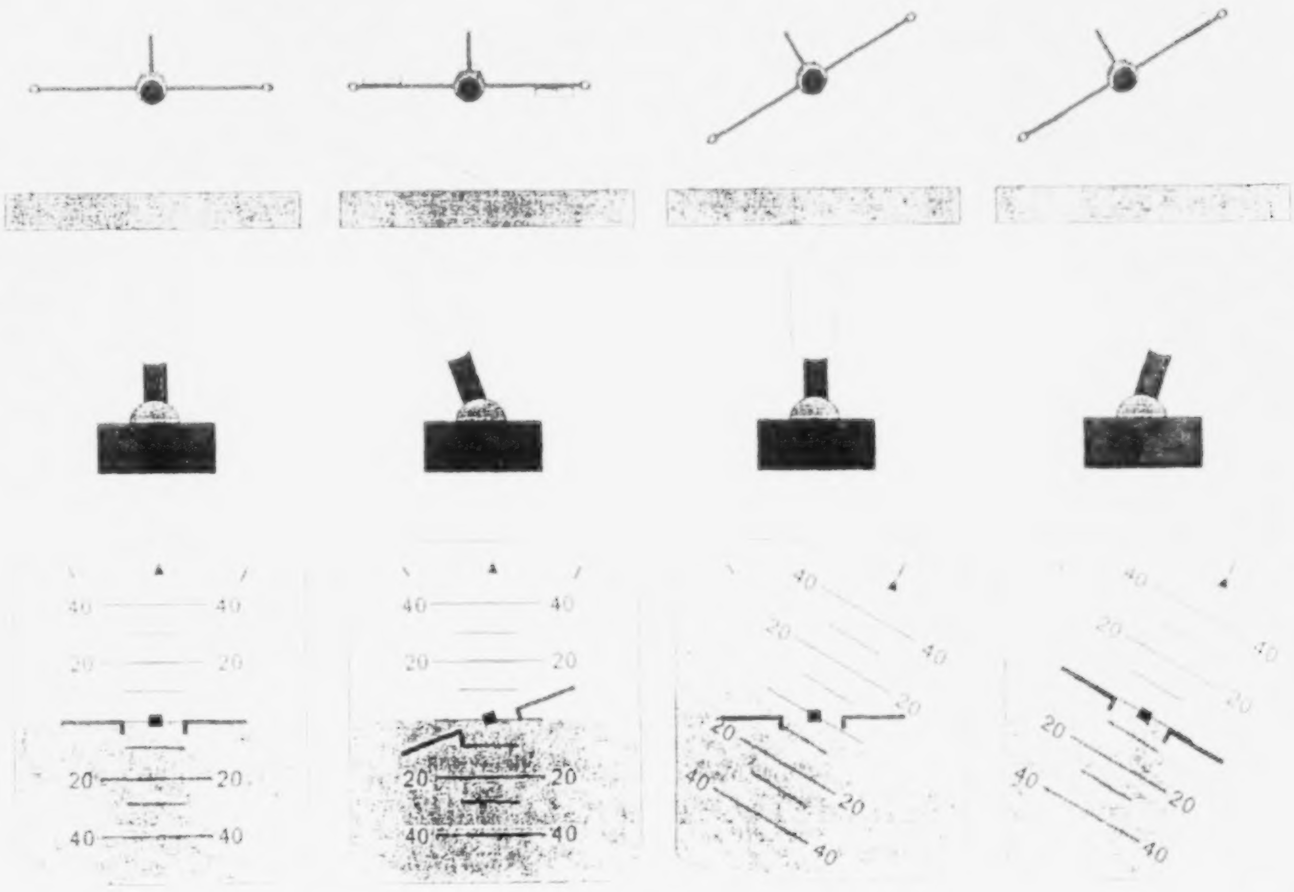
40

Frequency Separated ADI Display



Appendix E

Training Procedures

General Training Procedure

Introduction

- Go over all pilot briefing documents with subject
- Answer all questions
- Go over safety procedures, conduct cockpit briefing (refer to Safety Briefing)
  - Show locations of all switches
  - Show seat and control adjustments

Secondary Task Training

- Go over secondary task and joystick use (point out trim – Do not touch)
- Confirm: Out-the-window display is turned off (No Primary Task)
- Begin with visual secondary task (Run-code 723, 3 minutes)
- Encourage large drifts from centre, recovery from end-stops
- Repeat with audio secondary task (Run-code 725, 3 minutes)

Simulator Flight Training

- Confirm: No motion, no ADI, out-the-window display active (No Sec Task)
- Show and explain EFIS display, especially compass
- Begin with straight and level flight (Run-code 721, 3 minutes)
- Free flight, encourage smooth turns (Run-code 721, 3 minutes)
- Commanded turns, give verbal bank angle indications (Run-code 711, 5 minutes)
  - Command turns in 20, 30, 40, 50 degrees bank
  - Command heading changes of 30 degree increments
  - Command turns in the manner, "Turn right to a heading of three-three-zero with 30 degrees bank. Turn now."
- Fly straight and level with visual secondary task active (Run-code 723, 3 minutes)
- Fly straight and level with audio secondary task active (Run-code 725, 3 minutes)
- Following this session in the simulator, subject is familiarized with the NASA TLX rating process

Motion Training

- Confirm: Motion on, no ADI, out-the-window display active
- Begin with straight and level flight (Run-code 722, 3 minutes)
- Free flight, encourage smooth turns (Run-code 722, 3 minutes)
- Commanded turns, give verbal bank angle indications (Run-code 712, 5 minutes)
  - Command turns in 20, 30, 40, 50 degrees bank
  - Command heading changes of 30 degree increments
  - Command turns in the manner, "Turn right to a heading of three-three-zero with 30 degrees bank. Turn now."
- Fly straight and level with visual secondary task active (Run-code 726, 3 minutes)
- Fly straight and level with audio secondary task active (Run-code 724, 3 minutes)

ADI Training Procedure

Introduction

- Explain verbally and with diagrams how ADI functions
- Refer to ADI Briefing notes and diagrams

Demonstration

- Confirm: Proper ADI is displayed, motion system is OFF, out-the-window display is active
- Experimenter operates simulator to show how to use ADI with out-the-window view as reference (Run-code 115 (H)/116(F), ignore secondary task; 3 minutes)
- Answer any questions
- Confirm: Proper ADI is displayed, motion system is OFF, out-the-window display is turned OFF
- Experimenter will then fly runs again in instrument conditions (Run-code audio 111(H)/112(F), visual 115(H)/116(F); 3 minutes total)
- Answer any questions
- After demonstration, test subjects will proceed directly to testing sessions

Appendix F

Run Codes

```
   Runcodes for T33/ADI experiment
   ----------------------------------------
   123456789   For explanation of fields see end of file

111e101NAN10          Type 1 turns
112e101NAN20
113e101NAY10
114e101NAY20
115e101NVN10
116e101NVN20
117e101NVY10
118e101NVY20

121e102NAN10          Type 2 turns
122e102NAN20
123e102NAY10
124e102NAY20
125e102NVN10
126e102NVN20
127e102NVY10
128e102NVY20

131e103NAN10          Type 3 turns
132e103NAN20
133e103NAY10
134e103NAY20
135e103NVN10
136e103NVN20
137e103NVY10
138e103NVY20

141e104NAN10          Type 4 turns
142e104NAN20
143e104NAY10
144e104NAY20
145e104NVN10
146e104NVN20
147e104NVY10
148e104NVY20

151e105NAN10          Type 5 turns
152e105NAN20
153e105NAY10
154e105NAY20
155e105NVN10
156e105NVN20
157e105NVY10
158e105NVY20

161e106NAN10          Type 6 turns
162e106NAN20
163e106NAY10
164e106NAY20
165e106NVN10
166e106NVN20
167e106NVY10
168e106NVY20
```

171e107NAN10	Type 7 turns
172e107NAN20	
173e107NAY10	
174e107NAY20	
175e107NVN10	
176e107NVN20	
177e107NVY10	
178e107NVY20	
181e108NAN10	Type 8 turns
182e108NAN20	
183e108NAY10	
184e108NAY20	
185e108NVN10	
186e108NVN20	
187e108NVY10	
188e108NVY20	
191e109NAN10	Type 9 turns
192e109NAN20	
193e109NAY10	
194e109NAY20	
195e109NVN10	
196e109NVN20	
197e109NVY10	
198e109NVY20	
201e110NAN10	Type 10 turns
202e110NAN20	
203e110NAY10	
204e110NAY20	
205e110NVN10	
206e110NVN20	
207e110NVY10	
208e110NVY20	
211e111NAN10	Type 11 turns
212e111NAN20	
213e111NAY10	
214e111NAY20	
215e111NVN10	
216e111NVN20	
217e111NVY10	
218e111NVY20	
221e112NAN10	Type 12 turns
222e112NAN20	
223e112NAY10	
224e112NAY20	
225e112NVN10	
226e112NVN20	
227e112NVY10	
228e112NVY20	
311e200YAN10	Level tracking task
312e200YAN20	

```
313e200YAY10
314e200YAY20
315e200YVN10
316e200YVN20
317e200YVY10
318e200YVY20

411e300NNN1L        Unusual attitude recovery
412e300NNN1R
413e300NNN2L
414e300NNN2R
415e300NNY1L
416e300NNY1R
417e300NNY2L
418e300NNY2R

511e400YAN1L        Sudden attitude upset
512e400YAN1R
513e400YAN2L
514e400YAN2R
515e400YAY1L
516e400YAY1R
517e400YAY2L
518e400YAY2R
519e400YVN1L
520e400YVN1R
521e400YVN2L
522e400YVN2R
523e400YVY1L
524e400YVY1R
525e400YVY2L
526e400YVY2R
         ---------- Training runs
711t101NNN10      Turns
712t101NNY10

713t101NAN10
714t101NAY10
715t101NVN10
716t101NVY10

721t200NNN10       Level tracking
722t200NNY10

723t200NAN10
724t200NAY10
725t200NVN10
726t200NVY10
```

Fields: 1 - Evaluation or training run (e/t)

2 - Type of maneuver
  - 1 - Turns
  - 2 - Level tracking
  - 3 - Unusual attitude recovery
  - 4 - Sudden attitude upset

3,4 - Type of turn (1 - 12)

5 - Turbulence (Y/N)

6 - Secondary task (A - audio, V - visual)

7 - Motion (Y/N)

8 - ADI type (1-conventional, 2-frequency separated)

9 - Roll direction (L/R/0)

Appendix G

Objective Measures Output

```
==============================================
Tue Feb 13 11:15:09 2001

/cael/people/stefan/armcop/mx_t33/MMe200YVY10.DAT.1
 MM317
   Cycle time (microsec):
      avg =  .16608E+05   max =   17684   min =   14579   sd =  .34432E+03

 Duration sample:  88.5
 *** Toggles OK ***

 Performance for level flying
Heading (deg)              2.74        2.06        7.68         -.89
Bank (deg)                 1.57        5.48       14.01        -9.40
Sec. Task                 21.42       22.19       63.00       -23.33
===================================
Tue Feb 13 11:19:51 2001

/cael/people/stefan/armcop/mx_t33/MMe111NVY10.DAT.1
 MM217
   Cycle time (microsec):
      avg =  .16606E+05   max =   17739   min =   14481   sd =  .34485E+03

 Duration of turn 1:  22.6
             turn 2:  43.9
             turn 3:  42.5
 *** Toggles OK ***

 Performance for linked turns
Turn 1 bank (deg)        -28.96         .23      -28.48       -29.33
Turn 2 bank (deg)         39.32        1.53       43.13        37.14
Turn 3 bank (deg)         48.27        1.01       50.22        46.50

Turn 1 sec. Task          -3.02        2.10        1.62        -8.22
Turn 2 sec. Task          -8.91        8.31        2.04       -36.63
Turn 3 sec. Task          -7.45        7.86        6.00       -28.16

Turn 1 hdgn (deg)        -29.17         .48      -28.70       -30.31
Turn 2 hdgn (deg)         59.90         .21       60.38        59.59
Turn 3 hdgn (deg)        182.48         .49      183.60       181.72

Post 1 sec. Task         -12.53        6.87        3.26       -29.59
Post 2 sec. Task           2.03       17.05       27.01       -37.26
Post 3 sec. Task          -6.95       15.69       14.91       -60.36
```

```
 ==============================================
 Tue Feb 13 11:21:55 2001

 /cael/people/stefan/armcop/mx_t33/MMe400YVY1R.DAT.1
  MM524
    Cycle time (microsec):
       avg =  .16609E+05   max =   17555   min =   13864   sd =  .34513E+03

  Duration sample:   8.8
  *** Toggles OK ***

  Performance for sudden upset
 Roll     (deg)              27.92        25.78        73.46        -5.88
 Pitch    (deg)              16.75         7.80        24.44         2.83
 Aileron inputs         -.2248E-01   .2213E-01   .2420E-01   -.6686E-01
 ==============================================
 Tue Feb 13 11:33:56 2001

 /cael/people/stefan/armcop/mx_t33/MMe300NNY1L.DAT.1
  MM415
    Cycle time (microsec):
       avg =  .16625E+05   max =   17621   min =   14684   sd =  .34828E+03

  Duration sample:   7.0
  *** Toggles OK ***

  Performance for unblank maneuver
 Roll     (deg)             -28.16        28.78         5.01       -68.30
 Aileron inputs          .2193E-01   .5163E-01   .1277E+00   -.7684E-01
 ==============================================
```

Appendix H

Turn Types

Turn Types

Type 1

New Heading	*Bank Angle*	*Turn Direction*
0-3-0	20	Right
0-6-0	30	Right
0-0-0	40	Left

Type 2

New Heading	*Bank Angle*	*Turn Direction*
0-6-0	40	Right
0-9-0	30	Right
0-6-0	20	Left

Type 3

New Heading	*Bank Angle*	*Turn Direction*
3-3-0	20	Left
3-0-0	30	Left
0-0-0	40	Right

Type 4

New Heading	*Bank Angle*	*Turn Direction*
3-0-0	40	Left
2-7-0	30	Left
3-0-0	20	Right

Type 5

New Heading	*Bank Angle*	*Turn Direction*
3-3-0	20	Left
0-6-0	50	Right
0-0-0	30	Left

Type 6

New Heading	*Bank Angle*	*Turn Direction*
3-0-0	30	Left
3-3-0	20	Right
2-4-0	50	Left

Type 7

New Heading	*Bank Angle*	*Turn Direction*
0-3-0	20	Right
3-0-0	50	Left
0-0-0	30	Right

Type 8

New Heading	*Bank Angle*	*Turn Direction*
0-6-0	30	Right
0-3-0	20	Left
1-2-0	50	Right

Type 9

New Heading	*Bank Angle*	*Turn Direction*
0-3-0	30	Right
3-0-0	40	Left
1-8-0	50	Left

Type 10

New Heading	*Bank Angle*	*Turn Direction*
0-9-0	40	Right
3-3-0	50	Left
0-0-0	30	Right

Type 11

New Heading	*Bank Angle*	*Turn Direction*
3-3-0	30	Left
0-6-0	40	Right
1-8-0	50	Right

Type 12

New Heading	*Bank Angle*	*Turn Direction*
2-7-0	40	Left
0-3-0	50	Right
0-0-0	30	Left

Appendix I

TLX Instructions for Pilots

SUBJECT INSTRUCTIONS: RATINGS

We are not only interested in assessing your performance but also the experiences you had during the different task conditions. Right now we are going to describe the technique that will be used to examine your experiences. In the most general sense we are examining the "Workload" you experienced. Workload is a difficult concept to define precisely, but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put in, or the stress and frustration you felt. The workload contributed by different task elements may change as you get more familiar with a task, perform easier or harder versions of it, or move from one task to another. Physical components of workload are relatively easy to conceptualize and evaluate. However, the mental components of workload may be more difficult to measure.

Since workload is something that is experienced individually by each person, there are no effective "rulers" that can be used to estimate the workload of different activities. One way to find out about workload is to ask people to describe the feelings they experienced. Because workload may be caused by many different factors, we would like you to evaluate several of them individually rather than lumping them into a single global evaluation of overall workload. Attached to this document you will find a set of nine rating scales that were developed for you to use in evaluating your experiences during different tasks. Each is accompanied by a detailed description to help you gauge its meaning – please read these carefully. If you have a question about any of the scales, please ask about it. It is extremely important that they be clear to you.

After performing the task, you will be seated at a computer that will display each of the nine rating scales and their descriptions one at a time. You will evaluate the task by marking each scale at the point which matches your experience. Each line has two endpoint descriptors that describe the scale. Note that "Performance" goes from "good" on the left to "bad" on the right. This order has been confusing for some people. Drag the slider bar marker from its position at the left of the scale to the right until it points at the desired location. When you are satisfied with your choice, press the **Next** button at the lower left of the display, and the next rating scale will appear.

Please consider your responses carefully in distinguishing among the task conditions. Consider each scale individually. Your ratings will play an important role in the evaluation being conducted, thus, your active participation is essential to the success of this experiment, and is greatly appreciated.

SUBJECT INSTRUCTIONS: SOURCES-OF-WORKLOAD

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended or the performance they achieved. Others feel that if they performed well the workload must have been low, and vice versa. Yet others feel that effort or feelings of frustration are the most important factors in workload, and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

After each set of tasks, you will complete an evaluation that has been developed by NASA to assess the relative importance of six particular factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to your experience of workload in the task(s) that you just performed. Each pair of scale titles will appear separately on the screen. Select- the rating scale title that represents the more important contributor to workload- for the specific task(s) you performed in this experiment.

Position the mouse pointer (arrow) over the large button labeled with the rating scale title that you feel is the most important of the two. Click down on the left mouse button to select this rating scale. If you wish to change your mind, simply click the other button. When you are satisfied with your choice, press the **Next** button at the lower left of the display, and a new pair of rating scale titles will appear.

After you have finished the entire series we will be able to use the pattern of your choices to create a weighted combination of the ratings from that task into a summary workload score. Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any *correct* pattern; we are only interested in your opinions. If you have any questions, please ask them before the evaluation is performed. Thank you for your participation.

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

VISUAL DEMAND	*Low/High*	How much effort did you have to put into gathering all of the visual information required for the task? Did it require casual glances, with easily read instruments and low priority monitoring, or continuous searching, with hard to read instruments and poor visibility?
AUDITORY DEMAND	*Low/High*	How much attention did you have to put into listening for relevant information during the task? Was there little important talk, with low ambient noise and few distracting sounds, or intense discussion, a noisy environment, and important ambient sounds and alarms?
GLOBAL WORKLOAD	*Low/High*	Considering all aspects, how would you rate the demands of the task? Was it easy and automatic, with little attention or thought required, or difficult and overwhelming, requiring full concentration and resulting in lots of errors?

Appendix J

TLX Experimenter's Instructions

TLX Experimenter's Instructions

1) Do the weights after the last session with a given configuration.

2) Remind the subject that the ratings are for the complete simulator mission including all maneuvers and secondary tasks just completed during the last session.

3) Read over the attached instructions.

4) Only bring out the Psycho-Physiological Response Questionnaire if the response to question #2 is yes.

5) If a Psycho-Physiological Questionnaire is filled out then staple it to the subject's questionnaire form.

Experimental Procedure

The usual sequence of events for collecting data with the NASA Task Load Index is as follows:

Instructions

Subjects read the scale definitions and instructions. A set of generic instructions is included in Appendix H. Some modifications may be necessary depending on your situation.

Familiarization

Subjects practice using the rating scales after performing a few tasks to insure that they have developed a standard technique for dealing with the scales.

Ratings

Subjects perform the experimental tasks, providing ratings on the six subscales following all task conditions of interest. The number of rating sheets needed equals the number of subjects * the number of task conditions (including practice).

Weights

Subjects complete the "Sources-of-Workload Evaluation" once for each task or group of tasks included in the experiment that share a common structure (although difficulty levels may vary). For example, in an experiment with several memory tasks and several tracking tasks, two Sources-of-Workload Evaluations would be performed; one for the memory tasks and one for the tracking tasks. One set of cards should be made in advance of the experiment for each subject * evaluation condition combination. The pairs of factors should be cut apart and presented individually in a different, randomly selected, order to each subject. Subject instructions for doing the Sources-of-Workload Evaluations are in Appendix H. (Note that the exact time when the weights are obtained is not critical. However, in order for them to provide useful information, they must be obtained after at least some exposure to the relevant conditions.)

UTIAS NASA Task Load Index (TLX)
Evaluation Software Version 1.0

This brief document describes how to use the newly developed UTIAS adaptation of NASA's Task Load Index (TLX) software. The program is used to evaluate experimental subject's perception of the workload associated with a task along several different measurement axes. The rationale behind the evaluation methodology can be found in NASA's documentation of the TLX, which is available from Dr. Lloyd Reid at UTIAS. This document covers only those aspects of the TLX that are required to use the software.

1. STARTING THE PROGRAM

- The software (called the TLX Workload program) is currently installed on the simpc4 computer in Room 137D of the UTIAS Flight Simulation Laboratory. Locate this computer and turn it on if necessary. Wait for Windows 98 to start up.
- If someone is already logged on to the computer, log them off by choosing "Log Off" form the "Start" menu at the lower left of the screen. When prompted with the login screen, do not attempt to enter a username and password – simply press the escape key, and you will be logged in as a guest user.
- Locate the program's icon on the desktop. The icon consists of the letters "TLX" in red and blue lettering, and the word "Workload" in the caption below. To start the program, double-click on the icon, or right-click on it and choose "Open" from the pop-up menu.
- A small dialog window will open prompting you to enter the initials of the subject that is to be evaluated. Enter the subject's initials – they will appear in uppercase regardless of whether you are pressing the Shift key. If this is the first time this subject has been evaluated, a window will pop up warning you that there is no record of this subject in the database, and will ask you if you would like to create a new file for this subject. If this is in fact a new subject that has not yet performed any evaluations, click the "Yes" button to create a new file for this subject. If this warning window appears for a subject that should already be in the database, check to make sure that you have entered the initials correctly. If not, click "No" and re-enter the initials.
- Once you have entered a set of initials, the main program display will appear on the screen. The display has the same basic layout as many other common programs such as Microsoft Word or Corel WordPerfect. The top line of the display shows the program icon at the left, the current subject's file name, and the name of the program.

The next two lines down are a menu bar containing a set of standard pull-down menus, and a toolbar containing a set of short-cut buttons for some of the most commonly used menu commands. As you pass the mouse pointer over each item in the pull-down menus, the item will become highlighted, and a description of the purpose of that item will appear at the bottom of the display.

Furthermore, if you hold the mouse pointer (arrow) over any of the toolbar buttons, a brief description of its purpose will appear in a small yellow box beside the mouse pointer, and a longer description will appear at the bottom of the display.

- Below the tool bar, the display is split into two panes which are headed by the titles "Weights" on the left and "Ratings" on the right. These refer to the two types of evaluations that make up the TLX. Each of the two panes will contain the set of evaluations that must be completed for each subject participating in the ADI experiments, eight weights evaluations and sixteen ratings evaluations. To the left of each entry in each of the panes you will see either a red question mark, indicating that this evaluation has not yet been performed for the current subject, or a green check mark, indicating that the evaluation has been performed.
- From this point, you have four choices regarding what to do next. First, you can exit the program by choosing "Exit" from the "File" menu, or by clicking the close box marked "X" in the upper right corner of the display. Second, you can choose to begin (or continue) evaluation of a different subject by choosing "New Subject" from the "File" menu or by clicking the matching toolbar button (the one with the smiling face). This will cause the subject initials window to open again. Third and fourth, you can begin the evaluation of either ratings or weights for the current subject, as documented further in Sections 2 and 3, respectively.

2. EVALUATING RATINGS

- Each subject participating in the ADI experiments must complete one set of workload ratings after each session of experiments. When the subject is ready for this evaluation, they should present you with a form indicating which sessions they have completed and which they have not completed, and they should be able to tell you which one they have just finished. The name of the session they have just completed should match one of the entries under the "Ratings" pane of the program display. For example, one session is called "HN Session 1", indicating that it is this subject's first session using the moving horizon display with no motion base movement.
- Locate the name of the session that the current subject has just completed in the "Ratings" pane of the program display. Click on it with the mouse to select it, and it will become highlighted. To begin the ratings evaluation, you may either double-click on this entry in the "Ratings" pane, choose "Evaluate Ratings" from the "Workload" menu, or click the matching toolbar button (the one with the picture of a gauge with a small downward pointing red arrow).
- A new window will open titled with the words "Evaluate Ratings For" and the name of this ratings entry. Below this, the question "How would you rate this factor?" is posed in bold black letters. The scale name, its description, and the slider bar used for rating appear in a box below.
- At this point control should be turned over to the experimental subject. Instruct the subject to take note of the name of this rating scale in bold print at the left of the box,

and to read carefully its description at the right. When the subject is satisfied that they understand the meaning of this rating scale and the questions being asked, instruct them to drag the pointer at the far left of the slider bar to the right with the mouse until they have reached the position on the scale they feel matches their answer to the questions posed about this workload rating. Once the mouse button is released, the "Next" button will become active, and they can press it to proceed with the next rating scale.

- There are a total of nine scales for the subject to fill out. Once they have finished the last one, the ratings window will close, and the entry in the "Ratings" pane of the main display that has just been filled out will have a green check mark beside it to indicate that this evaluation has been completed.

3. EVALUATING WEIGHTS

- In addition to the ratings scales described above, each subject participating in the ADI experiments must also answer a series of questions comparing the relative importance of each item in successive pairs of the rating scales in the experimental tasks that they have just completed. This evaluation serves to weight the contribution of each rating scale to the overall workload index. The names of the weighting evaluations that must be completed by each subject appear in the "Weights" pane of the main program display.
- Each time a subject completes a ratings evaluation that has the words "Evaluate weights" in its title in parentheses, the subject must also perform a weights evaluation. The choice of weights evaluation to be performed should again be based on the type of experimental session the subject has just completed. For example, if the subject has just completed a session using the frequency separated ADI with motion turned on and with a visual side task, the set of weights entitled "FMV (Frequency Separated / Motion / Visual) should be evaluated.
- Locate the name of the appropriate set of weights in the "Weights" pane of the program display. Click on it with the mouse to select it, and it will become highlighted. To begin the weights evaluation, you may either double-click on this entry in the "Weights" pane, choose "Evaluate Weights" from the "Workload" menu, or click the matching toolbar button (the one with the picture of a balance).
- A new window will open titled with the words "Evaluate Weights For" and the name of this weights entry. Below this, the question "Which factor was most important?" is posed in bold black letters. Two large buttons appear in two boxes below, each labeled with name of one of the ratings scales, and a description of each of the scales appears to the right.
- At this point control should be turned over to the experimental subject. Instruct the subject to take note of the names of the two ratings scales in bold print on the buttons, and to read carefully their descriptions at the right. When the subject is satisfied that they understand the meanings of both rating scales and the questions being asked, instruct them to click on the button corresponding to the scale they consider to be the more important of the two for the tasks they have just completed. Once one of the

buttons has been clicked, it will become depressed, its caption will be underlined, and the name of this scale will appear as an answer to the question posed at the top of the window. The "Next" button will then become active, and the subject can press it to proceed with the next comparison. The comparisons are presented in random order.

- There are a total of fifteen comparisons for the subject to evaluate. Once they have finished the last one, the weights window will close, and the entry in the "Weights" pane of the main display that has just been filled out will have a green check mark beside it to indicate that this evaluation has been completed.

4. COMPUTING THE TASK LOAD INDEX

- The computation of the NASA Task Load Index requires both a set of six ratings and a set of weights for each of these ratings (the three additional ratings "Visual Demand", "Auditory Demand", and "Global Workload" that were filled out are supplementary and not associated with the NASA TLX). The TLX is calculated as the weighted sum of the six ratings. In order to compute the index, you must therefore select both a set of ratings and its associated set of weights. The weights are computed by the program automatically from the results of the pairwise comparison tests.
- The set of ratings and weights should match, such that if the set of ratings was evaluated for an experimental session with, for example, the moving horizon display, the motion base on, and the audio side task, then these ratings should be matched with the similarly named set of weights. Note that in order to determine which side task was employed with which session, the documentation of the ADI experiment will need to be consulted. There will be two sets of ratings matched to each set of weights.
- To compute the TLX, first identify a set of ratings in the "Ratings" pane and a matching set of weights in the "Weights" pane. Click on one and then the other (the order does not matter) so that each becomes highlighted. If both the set of ratings and the set of weights have been completed (each should be accompanied by a green check mark), then the TLX can be computed.
- To proceed with the computation of the TLX, you may either select the "Compute Workload" entry from the "Workload" menu, or click the matching toolbar button (the one with a capital sigma "Σ" on it). A new window will open with the title "Computed Workload", displaying the names of the subject, weights, and ratings, the values of all the weights and ratings, and the computed TLX value at the lower right.
- From this point you have two choices. You may either simply close this window by clicking the "Close" button and continue with more evaluations, or you may save the data that has just been computed to a file by clicking the "Save" button. If you choose to save the data, it will be written out to a file entitled "ADIResults.txt". All output data from all subjects and all weights-ratings pairs are written to this file in tabular form, such that one new line is added each time you choose to save the results of a computed workload.

- This file can be inspected with any simple text editor program, or imported into a spreadsheet program such as Microsoft Excel. If you choose to import the file into to Excel, be sure to specify that the file uses delimiters, *not* fixed width columns, and that the delimiting character is a comma ",".

Appendix K

TLX Summary Printout

```
     ******************* WARNING! *****************
     * THIS FILE IS MACHINE-GENERATED. DO NOT EDIT *
     * ANY PART OF IT OR IT MAY BECOME UNREADABLE! *
     ***********************************************

FILE_NAME LS.tlx

BEGIN_WEIGHTS
      WEIGHTS_GROUP_NAME HNA (Moving Horizon / No Motion / Audio)
      WEIGHTS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PHYSICAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND YES
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      PERFORMANCE_MORE_IMPORTANT_THAN_EFFORT NO
      PERFORMANCE_MORE_IMPORTANT_THAN_FRUSTRATION NO
      EFFORT_MORE_IMPORTANT_THAN_FRUSTRATION YES
END_WEIGHTS

BEGIN_WEIGHTS
      WEIGHTS_GROUP_NAME HNV (Moving Horizon / No Motion / Visual)
      WEIGHTS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PHYSICAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      PERFORMANCE_MORE_IMPORTANT_THAN_EFFORT NO
      PERFORMANCE_MORE_IMPORTANT_THAN_FRUSTRATION YES
      EFFORT_MORE_IMPORTANT_THAN_FRUSTRATION YES
END_WEIGHTS

BEGIN_WEIGHTS
      WEIGHTS_GROUP_NAME HMA (Moving Horizon / Motion / Audio)
      WEIGHTS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PHYSICAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION NO
      PERFORMANCE_MORE_IMPORTANT_THAN_EFFORT NO
      PERFORMANCE_MORE_IMPORTANT_THAN_FRUSTRATION YES
      EFFORT_MORE_IMPORTANT_THAN_FRUSTRATION YES
END_WEIGHTS

BEGIN_WEIGHTS
      WEIGHTS_GROUP_NAME HMV (Moving Horizon / Motion / Visual)
      WEIGHTS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PHYSICAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      PERFORMANCE_MORE_IMPORTANT_THAN_EFFORT NO
      PERFORMANCE_MORE_IMPORTANT_THAN_FRUSTRATION YES
      EFFORT_MORE_IMPORTANT_THAN_FRUSTRATION YES
END_WEIGHTS

BEGIN_WEIGHTS
      WEIGHTS_GROUP_NAME FNA (Frequency Separated / No Motion / Audio)
      WEIGHTS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PHYSICAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
      TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION NO
      PERFORMANCE_MORE_IMPORTANT_THAN_EFFORT YES
      PERFORMANCE_MORE_IMPORTANT_THAN_FRUSTRATION YES
      EFFORT_MORE_IMPORTANT_THAN_FRUSTRATION YES
END_WEIGHTS

BEGIN_WEIGHTS
      WEIGHTS_GROUP_NAME FNV (Frequency Separated / No Motion / Visual)
      WEIGHTS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PHYSICAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE YES
      MENTAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT YES
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        MENTAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND NO
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
        TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
        TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
        TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
        PERFORMANCE_MORE_IMPORTANT_THAN_EFFORT YES
        PERFORMANCE_MORE_IMPORTANT_THAN_FRUSTRATION YES
        EFFORT_MORE_IMPORTANT_THAN_FRUSTRATION YES
END_WEIGHTS

BEGIN_WEIGHTS
        WEIGHTS_GROUP_NAME FMA (Frequency Separated / Motion / Audio)
        WEIGHTS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_PHYSICAL_DEMAND YES
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND YES
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND NO
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION NO
        TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
        TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
        TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION NO
        PERFORMANCE_MORE_IMPORTANT_THAN_EFFORT YES
        PERFORMANCE_MORE_IMPORTANT_THAN_FRUSTRATION YES
        EFFORT_MORE_IMPORTANT_THAN_FRUSTRATION YES
END_WEIGHTS

BEGIN_WEIGHTS
        WEIGHTS_GROUP_NAME FMV (Frequency Separated / Motion / Visual)
        WEIGHTS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_PHYSICAL_DEMAND YES
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND YES
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
        MENTAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_TEMPORAL_DEMAND NO
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT NO
        PHYSICAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
        TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_PERFORMANCE NO
        TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_EFFORT YES
        TEMPORAL_DEMAND_MORE_IMPORTANT_THAN_FRUSTRATION YES
        PERFORMANCE_MORE_IMPORTANT_THAN_EFFORT YES
        PERFORMANCE_MORE_IMPORTANT_THAN_FRUSTRATION YES
        EFFORT_MORE_IMPORTANT_THAN_FRUSTRATION YES
END_WEIGHTS

BEGIN_RATINGS
        RATINGS_NAME HN Session 1
        RATINGS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND 65
        PHYSICAL_DEMAND 26
        TEMPORAL_DEMAND 66
        PERFORMANCE 30
        EFFORT 60
        FRUSTRATION 30
        VISUAL_DEMAND 65
        AUDITORY_DEMAND 25
        GLOBAL_WORKLOAD 65
END_RATINGS

BEGIN_RATINGS
        RATINGS_NAME HN Session 2
        RATINGS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND 50
        PHYSICAL_DEMAND 35
        TEMPORAL_DEMAND 50
        PERFORMANCE 25
        EFFORT 50
        FRUSTRATION 25
        VISUAL_DEMAND 40
        AUDITORY_DEMAND 70
        GLOBAL_WORKLOAD 53
END_RATINGS

BEGIN_RATINGS
        RATINGS_NAME HN Session 3  (Evaluate weights)
        RATINGS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND 45
        PHYSICAL_DEMAND 31
        TEMPORAL_DEMAND 50
        PERFORMANCE 29
        EFFORT 50
        FRUSTRATION 30
        VISUAL_DEMAND 47
        AUDITORY_DEMAND 70
        GLOBAL_WORKLOAD 50
END_RATINGS

BEGIN_RATINGS
        RATINGS_NAME HN Session 4  (Evaluate weights)
        RATINGS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND 65
        PHYSICAL_DEMAND 34
        TEMPORAL_DEMAND 63
        PERFORMANCE 30
        EFFORT 56
        FRUSTRATION 39
        VISUAL_DEMAND 66
        AUDITORY_DEMAND 27
        GLOBAL_WORKLOAD 45
END_RATINGS

BEGIN_RATINGS
        RATINGS_NAME HM Session 1
        RATINGS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND 36
        PHYSICAL_DEMAND 34
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       TEMPORAL_DEMAND 49
       PERFORMANCE 31
       EFFORT 43
       FRUSTRATION 28
       VISUAL_DEMAND 45
       AUDITORY_DEMAND 68
       GLOBAL_WORKLOAD 49
END_RATINGS

BEGIN_RATINGS
       RATINGS_NAME HM Session 2
       RATINGS_HAVE_BEEN_EVALUATED? YES
       MENTAL_DEMAND 65
       PHYSICAL_DEMAND 28
       TEMPORAL_DEMAND 59
       PERFORMANCE 24
       EFFORT 47
       FRUSTRATION 30
       VISUAL_DEMAND 72
       AUDITORY_DEMAND 25
       GLOBAL_WORKLOAD 65
END_RATINGS

BEGIN_RATINGS
       RATINGS_NAME HM Session 3  (Evaluate weights)
       RATINGS_HAVE_BEEN_EVALUATED? YES
       MENTAL_DEMAND 46
       PHYSICAL_DEMAND 26
       TEMPORAL_DEMAND 60
       PERFORMANCE 24
       EFFORT 41
       FRUSTRATION 26
       VISUAL_DEMAND 43
       AUDITORY_DEMAND 65
       GLOBAL_WORKLOAD 45
END_RATINGS

BEGIN_RATINGS
       RATINGS_NAME HM Session 4  (Evaluate weights)
       RATINGS_HAVE_BEEN_EVALUATED? YES
       MENTAL_DEMAND 35
       PHYSICAL_DEMAND 25
       TEMPORAL_DEMAND 40
       PERFORMANCE 25
       EFFORT 43
       FRUSTRATION 29
       VISUAL_DEMAND 65
       AUDITORY_DEMAND 21
       GLOBAL_WORKLOAD 48
END_RATINGS

BEGIN_RATINGS
       RATINGS_NAME FN Session 1
       RATINGS_HAVE_BEEN_EVALUATED? YES
       MENTAL_DEMAND 45
       PHYSICAL_DEMAND 25
       TEMPORAL_DEMAND 20
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      PERFORMANCE 25
      EFFORT 50
      FRUSTRATION 20
      VISUAL_DEMAND 70
      AUDITORY_DEMAND 30
      GLOBAL_WORKLOAD 40
END_RATINGS

BEGIN_RATINGS
      RATINGS_NAME FN Session 2
      RATINGS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND 24
      PHYSICAL_DEMAND 24
      TEMPORAL_DEMAND 26
      PERFORMANCE 26
      EFFORT 30
      FRUSTRATION 20
      VISUAL_DEMAND 26
      AUDITORY_DEMAND 75
      GLOBAL_WORKLOAD 30
END_RATINGS

BEGIN_RATINGS
      RATINGS_NAME FN Session 3  (Evaluate weights)
      RATINGS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND 25
      PHYSICAL_DEMAND 25
      TEMPORAL_DEMAND 29
      PERFORMANCE 25
      EFFORT 35
      FRUSTRATION 25
      VISUAL_DEMAND 25
      AUDITORY_DEMAND 75
      GLOBAL_WORKLOAD 35
END_RATINGS

BEGIN_RATINGS
      RATINGS_NAME FN Session 4  (Evaluate weights)
      RATINGS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND 35
      PHYSICAL_DEMAND 23
      TEMPORAL_DEMAND 26
      PERFORMANCE 23
      EFFORT 26
      FRUSTRATION 23
      VISUAL_DEMAND 72
      AUDITORY_DEMAND 34
      GLOBAL_WORKLOAD 46
END_RATINGS

BEGIN_RATINGS
      RATINGS_NAME FM Session 1
      RATINGS_HAVE_BEEN_EVALUATED? YES
      MENTAL_DEMAND 35
      PHYSICAL_DEMAND 40
      TEMPORAL_DEMAND 60
      PERFORMANCE 20
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        EFFORT 40
        FRUSTRATION 20
        VISUAL_DEMAND 70
        AUDITORY_DEMAND 14
        GLOBAL_WORKLOAD 60
END_RATINGS

BEGIN_RATINGS
        RATINGS_NAME FM Session 2
        RATINGS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND 25
        PHYSICAL_DEMAND 24
        TEMPORAL_DEMAND 25
        PERFORMANCE 15
        EFFORT 25
        FRUSTRATION 10
        VISUAL_DEMAND 15
        AUDITORY_DEMAND 75
        GLOBAL_WORKLOAD 25
END_RATINGS

BEGIN_RATINGS
        RATINGS_NAME FM Session 3  (Evaluate weights)
        RATINGS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND 40
        PHYSICAL_DEMAND 30
        TEMPORAL_DEMAND 25
        PERFORMANCE 20
        EFFORT 45
        FRUSTRATION 15
        VISUAL_DEMAND 70
        AUDITORY_DEMAND 20
        GLOBAL_WORKLOAD 50
END_RATINGS

BEGIN_RATINGS
        RATINGS_NAME FM Session 4  (Evaluate weights)
        RATINGS_HAVE_BEEN_EVALUATED? YES
        MENTAL_DEMAND 35
        PHYSICAL_DEMAND 25
        TEMPORAL_DEMAND 25
        PERFORMANCE 20
        EFFORT 25
        FRUSTRATION 30
        VISUAL_DEMAND 20
        AUDITORY_DEMAND 75
        GLOBAL_WORKLOAD 29
END_RATINGS
```

Appendix L

ADI Questionnaire

NAME:

SESSION:

DATE:

ADI QUESTIONNAIRE

1) Free comments on the flying tasks, the secondary task and the ADI display.

2) Did you feel disoriented or uncomfortable at any time? If so, complete the following Psycho-Physiological Response Questionnaire.

Psychophysiological Response Questionnaires

1 In the past have you experienced, (Please check)	Yes	No
• Motion sickness in an aircraft, no visual aids	☐	☐
• Motion sickness in an aircraft, with visual aids	☐	☐
• Vertigo (spatial disorientation) in an aircraft, no visual aids	☐	☐
• Vertigo in an aircraft, with visual aids	☐	☐
• Simulator sickness (motion sickness in a simulator)	☐	☐

2 While flying or viewing the visual system, did you experience any of the following

	Slight	Moderate	Strong	Nothing	Onset time/Maneuver
• Uneasiness	☐	☐	☐	☐	________________
• Dizziness	☐	☐	☐	☐	________________
• Sweating	☐	☐	☐	☐	________________
• Headache	☐	☐	☐	☐	________________
• Eye strain	☐	☐	☐	☐	________________
• Imbalance	☐	☐	☐	☐	________________
• Stomach awareness	☐	☐	☐	☐	________________
• Nausea	☐	☐	☐	☐	________________
• Vertigo	☐	☐	☐	☐	________________

3. *Comments*
(use back of form if necessary)

4. *Describe the characteristics of the simulation that you believe caused the problem(s).*
(use back of form if necessary)

Appendix M

Experimenter's Material

Motion System and Control Loader

- warm up system
- inspection - base and cockpit
- heave cycle
- prerecorded flight

T-33 System

- start MaxVue
- load SIMex-PLUS T-33
- confirm sound system (volume 12)

Motion Base Control

Motion Control Panel : STATUS - READY MODE - MAINT
Motion Test Panel :HEAVE - TEST - ATTD
Buffet : OFF

To bring base up:

- belts across door
- walkway up
- confirm HEAVE - TEST - ATTD
- select STATUS - ON

To start:

- toggle COMPTR for motion on

To bring base down:

- stop motion by selecting TEST
- select STATUS - OFF

Flight

- safety briefing; including stick and emergency buttons, seat adjustments, EFIS layout
- check trim settings on both sticks
- ADI on/off as required
- reconfirm proper runcode and conditions
- bring moving map on iris5
- have pilot confirm locked seat and secure harness
- confirm lights off and air conditioning on
- have pilot set controls, hands off
- select configuration
- bring motion base up and select COMPTR
- hands on, begin pilot control
- tell pilot to remain seated with seat belts on until door is opened
- stop motion and bring base down

Test Subject Progress Sheet

Name: Luke Stras

Initial Block: FM

Description	Date Completed	Initial
Simulator Introduction		
Secondary Task Training		
Non-motion Flight Training (Complete TLX for Practice)		
Motion Flight Training		
Frequency Separated ADI Intro		
FM Session 1 [V]		
FM Session 2 [A]		
FM Session 3 [V] (Complete TLX Weights)		
FM Session 4 [A] (Complete TLX Weights)		
FN Session 1 [V]		
FN Session 2 [A]		
FN Session 3 [A] (Complete TLX Weights)		
FN Session 4 [V] (Complete TLX Weights)		
Moving Horizon ADI Intro		
HN Session 1 [V]		
HN Session 2 [A]		
HN Session 3 [A] (Complete TLX Weights)		
HN Session 4 [V] (Complete TLX Weights)		
HM Session 1 [A]		
HM Session 2 [V]		
HM Session 3 [A] (Complete TLX Weighting)		
HM Session 4 [V] (Complete TLX Weighting)		

Test Subject Log Sheet Page 1

Name: Luke Stras **Initial Block:** FM

Date	Time	Description	Runcode	Rep #	Mean	SD	Max	Min	Comments
14-Feb-01	9:49	Visual Task Training	LS725						
	9:53	Audio Task Training	LS723						
	9:57	Straight & Level Training	LS721						
	10:00	Free Flight Training	LS721						
	10:05	Commanded Turns Training	LS711						
	10:08	Free Flight with Visual	LS725						
	10:13	Free Flight with Audio	LS723						
	10:34	Motion Straight Training	LS722						
	10:37	Motion Free Flight Training	LS722						
	10:42	Motion Turns Training	LS712						
	10:45	Motion with Visual	LS726						
	10:49	Motion with Audio	LS724						
	11:01	FM1 Vis - Level Tracking	LS318	1	1.46	4.38	8.42	-6.48	
	11:04	FM1 Vis - Turn 1	LS118	1	0.75	0.22	1.08	0.21	
	11:08	FM1 Vis - Level Tracking	LS318	2	0.57	0.92	2.73	-1.43	

Appendix N

SPSS Analysis of Variance
Significance Values and Mean Square Errors

Significance Values for Continuous Events

	HFIRST	ADI	ADI * HFIRST	MOTION	MOTION * HFIRST
20 Bank Mean	0.867	0.661	0.969	0.168	0.942
20 Bank SD	0.76	0.082	0.024	0.936	0.077
20 Bank Sec Mean	0.641	0.859	0.899	0.195	0.092
20 Bank Sec SD	0.737	0.436	0	0.8	0.603
20 Heading Mean	0.634	0.136	0.693	0.486	0.826
20 Heading SD	0.51	0.496	0.178	0.166	0.331
20 Heading Sec Mean	0.403	0.238	0.65	0.638	0.505
20 Heading Sec SD	0.258	0.307	0.003	0.81	0.763
30 Bank Mean	0.174	0.716	0.088	0.458	0.893
30 Bank SD	0.339	0.548	0.006	0.01	0.479
30 Bank Sec Mean	0.213	0.193	0.175	0.629	0.405
30 Bank Sec SD	0.494	0.331	0.014	0.582	0.398
30 Heading Mean	0.637	0.715	0.865	0.3	0.678
30 Heading SD	0.952	0.985	0.033	0.691	0.856
30 Heading Sec Mean	0.747	0.291	0.544	0.679	0.307
30 Heading Sec SD	0.642	0.314	0.095	0.727	0.411
40 Bank Mean	0.944	0.305	0.146	0.066	0.298
40 Bank SD	0.516	0.305	0.043	0.04	0.201
40 Bank Sec Mean	0.883	0.7	0.991	0.77	0.864
40 Bank Sec SD	0.95	0.366	0.007	0.044	0.345
40 Heading Mean	0.267	0.47	0.699	0.447	0.171
40 Heading SD	0.585	0.337	0.026	0.519	0.148
40 Heading Sec Mean	0.722	0.065	0.517	0.225	0.936
40 Heading Sec SD	0.698	0.349	0.05	0.435	0.484
50 Bank Mean	0.751	0.046	0.302	0.615	0.544
50 Bank SD	0.365	0.716	0.004	0.861	0.569
50 Bank Sec Mean	0.405	0.758	0.018	0.259	0.432
50 Bank Sec SD	0.936	0.189	0.003	0.686	0.678
50 Heading Mean	0.233	0.259	0.49	0.114	0.294
50 Heading SD	0.613	0.789	0.089	0.076	0.65
50 Heading Sec Mean	0.438	0.689	0.364	0.012	0.645
50 Heading Sec SD	0.651	0.507	0.012	0.222	0.563
Level Bank Mean	0.237	0.058	0.114	0.207	0.744
Level Bank SD	0.469	0.441	0.009	0.939	0.972
Level Heading Mean	0.122	0.058	0.37	0.279	0.856
Level Heading SD	0.396	0.002	0.049	0.662	0.43
Level Sec Mean	0.22	0.746	0.418	0.162	0.693
Level Sec SD	0.392	0.755	0.166	0.885	0.689

Significance Values for Continuous Events

	SECTASK	SECTASK * HFIRST	ADI * MOTION	ADI * MOTION * HFIRST	ADI * SECTASK
20 Bank Mean	0.975	0.846	0.674	0.431	0.501
20 Bank SD	0.712	0.859	0.949	0.233	0.955
20 Bank Sec Mean	**0.001**	0.714	0.154	0.365	0.533
20 Bank Sec SD	0.444	0.751	0.589	0.688	0.406
20 Heading Mean	0.352	0.29	0.846	0.455	0.51
20 Heading SD	0.569	0.336	0.383	0.92	0.307
20 Heading Sec Mean	**0.076**	0.207	0.794	0.839	0.985
20 Heading Sec SD	0.867	0.39	0.874	0.942	0.591
30 Bank Mean	0.889	0.95	0.802	0.27	0.489
30 Bank SD	**0.043**	0.317	0.533	0.905	0.265
30 Bank Sec Mean	**0.028**	0.995	0.991	0.863	0.958
30 Bank Sec SD	0.955	0.577	0.254	0.845	0.852
30 Heading Mean	0.825	0.887	0.459	0.676	0.753
30 Heading SD	0.623	0.323	0.469	0.573	0.203
30 Heading Sec Mean	0.309	0.143	0.202	0.313	0.567
30 Heading Sec SD	0.386	0.548	0.457	0.453	0.915
40 Bank Mean	0.123	0.324	0.271	**0.008**	0.874
40 Bank SD	**0.023**	0.156	0.492	0.465	0.615
40 Bank Sec Mean	**0.01**	0.464	0.34	0.741	0.708
40 Bank Sec SD	0.602	0.521	0.653	**0.011**	0.25
40 Heading Mean	0.189	0.194	0.304	0.114	0.42
40 Heading SD	0.592	0.252	0.278	0.628	0.384
40 Heading Sec Mean	0.998	0.943	**0.069**	0.815	0.24
40 Heading Sec SD	0.83	0.714	0.452	**0.016**	0.449
50 Bank Mean	0.291	0.103	0.532	0.773	0.711
50 Bank SD	**0.029**	0.158	0.597	0.271	0.346
50 Bank Sec Mean	**0.02**	0.47	0.664	0.257	0.987
50 Bank Sec SD	0.613	0.131	0.435	0.424	0.316
50 Heading Mean	**0.049**	0.337	0.368	0.176	0.477
50 Heading SD	0.749	0.178	0.952	0.825	0.447
50 Heading Sec Mean	0.122	0.218	0.191	0.927	0.539
50 Heading Sec SD	0.443	0.404	0.566	0.244	0.789
Level Bank Mean	0.903	0.674	0.523	0.58	0.396
Level Bank SD	**0.04**	**0.07**	0.45	0.418	0.872
Level Heading Mean	0.867	0.902	0.652	0.775	0.619
Level Heading SD	0.901	0.193	0.865	0.186	0.582
Level Sec Mean	**0.075**	0.715	0.114	0.808	**0.078**
Level Sec SD	**0.015**	0.275	0.604	0.103	0.961

Significance Values for Continuous Events

	HFIRST	ADI	ADI * HFIRST	MOTION	MOTION * HFIRST
20 Bank Mean	0.867	0.661	0.969	0.168	0.942
20 Bank SD	0.76	**0.082**	**0.024**	0.936	**0.077**
20 Bank Sec Mean	0.641	0.859	0.899	0.195	**0.092**
20 Bank Sec SD	0.737	0.436	**0**	0.8	0.603
20 Heading Mean	0.634	0.136	0.693	0.486	0.826
20 Heading SD	0.51	0.496	0.178	0.166	0.331
20 Heading Sec Mean	0.403	0.238	0.65	0.638	0.505
20 Heading Sec SD	0.258	0.307	**0.003**	0.81	0.763
30 Bank Mean	0.174	0.716	**0.088**	0.458	0.893
30 Bank SD	0.339	0.548	**0.006**	**0.01**	0.479
30 Bank Sec Mean	0.213	0.193	0.175	0.629	0.405
30 Bank Sec SD	0.494	0.331	**0.014**	0.582	0.398
30 Heading Mean	0.637	0.715	0.865	0.3	0.678
30 Heading SD	0.952	0.985	**0.033**	0.691	0.856
30 Heading Sec Mean	0.747	0.291	0.544	0.679	0.307
30 Heading Sec SD	0.642	0.314	**0.095**	0.727	0.411
40 Bank Mean	0.944	0.305	0.146	**0.066**	0.298
40 Bank SD	0.516	0.305	**0.043**	**0.04**	0.201
40 Bank Sec Mean	0.883	0.7	0.991	0.77	0.864
40 Bank Sec SD	0.95	0.366	**0.007**	**0.044**	0.345
40 Heading Mean	0.267	0.47	0.699	0.447	0.171
40 Heading SD	0.585	0.337	**0.026**	0.519	0.148
40 Heading Sec Mean	0.722	**0.065**	0.517	0.225	0.936
40 Heading Sec SD	0.698	0.349	**0.05**	0.435	0.484
50 Bank Mean	0.751	**0.046**	0.302	0.615	0.544
50 Bank SD	0.365	0.716	**0.004**	0.861	0.569
50 Bank Sec Mean	0.405	0.758	**0.018**	0.259	0.432
50 Bank Sec SD	0.936	0.189	**0.003**	0.686	0.678
50 Heading Mean	0.233	0.259	0.49	0.114	0.294
50 Heading SD	0.613	0.789	**0.089**	**0.076**	0.65
50 Heading Sec Mean	0.438	0.689	0.364	**0.012**	0.645
50 Heading Sec SD	0.651	0.507	**0.012**	0.222	0.563
Level Bank Mean	0.237	**0.058**	0.114	0.207	0.744
Level Bank SD	0.469	0.441	**0.009**	0.939	0.972
Level Heading Mean	0.122	**0.058**	0.37	0.279	0.856
Level Heading SD	0.396	**0.002**	**0.049**	0.662	0.43
Level Sec Mean	0.22	0.746	0.418	0.162	0.693
Level Sec SD	0.392	0.755	0.166	0.885	0.689

Significance Values for Continuous Events

	SECTASK	SECTASK * HFIRST	ADI * MOTION	ADI * MOTION * HFIRST	ADI * SECTASK
20 Bank Mean	0.975	0.846	0.674	0.431	0.501
20 Bank SD	0.712	0.859	0.949	0.233	0.955
20 Bank Sec Mean	0.001	0.714	0.154	0.365	0.533
20 Bank Sec SD	0.444	0.751	0.589	0.688	0.406
20 Heading Mean	0.352	0.29	0.846	0.455	0.51
20 Heading SD	0.569	0.336	0.383	0.92	0.307
20 Heading Sec Mean	0.076	0.207	0.794	0.839	0.985
20 Heading Sec SD	0.867	0.39	0.874	0.942	0.591
30 Bank Mean	0.889	0.95	0.802	0.27	0.489
30 Bank SD	0.043	0.317	0.533	0.905	0.265
30 Bank Sec Mean	0.028	0.995	0.991	0.863	0.958
30 Bank Sec SD	0.955	0.577	0.254	0.845	0.852
30 Heading Mean	0.825	0.887	0.459	0.676	0.753
30 Heading SD	0.623	0.323	0.469	0.573	0.203
30 Heading Sec Mean	0.309	0.143	0.202	0.313	0.567
30 Heading Sec SD	0.386	0.548	0.457	0.453	0.915
40 Bank Mean	0.123	0.324	0.271	0.008	0.874
40 Bank SD	0.023	0.156	0.492	0.465	0.615
40 Bank Sec Mean	0.01	0.464	0.34	0.741	0.708
40 Bank Sec SD	0.602	0.521	0.653	0.011	0.25
40 Heading Mean	0.189	0.194	0.304	0.114	0.42
40 Heading SD	0.592	0.252	0.278	0.628	0.384
40 Heading Sec Mean	0.998	0.943	0.069	0.815	0.24
40 Heading Sec SD	0.83	0.714	0.452	0.016	0.449
50 Bank Mean	0.291	0.103	0.532	0.773	0.711
50 Bank SD	0.029	0.158	0.597	0.271	0.346
50 Bank Sec Mean	0.02	0.47	0.664	0.257	0.987
50 Bank Sec SD	0.613	0.131	0.435	0.424	0.316
50 Heading Mean	0.049	0.337	0.368	0.176	0.477
50 Heading SD	0.749	0.178	0.952	0.825	0.447
50 Heading Sec Mean	0.122	0.218	0.191	0.927	0.539
50 Heading Sec SD	0.443	0.404	0.566	0.244	0.789
Level Bank Mean	0.903	0.674	0.523	0.58	0.396
Level Bank SD	0.04	0.07	0.45	0.418	0.872
Level Heading Mean	0.867	0.902	0.652	0.775	0.619
Level Heading SD	0.901	0.193	0.865	0.186	0.582
Level Sec Mean	0.075	0.715	0.114	0.808	0.078
Level Sec SD	0.015	0.275	0.604	0.103	0.961

Significance Values for Continuous Events

	ADI * SECTASK * HFIRST	MOTION * SECTASK	MOTION * SECTASK * HFIRST	ADI * MOTION * SECTASK	ADI * MOTION * SECTASK * HFIRST
20 Bank Mean	0.808	0.524	0.906	0.656	**0.002**
20 Bank SD	0.11	0.81	0.272	0.444	0.757
20 Bank Sec Mean	0.988	0.897	0.172	0.843	0.775
20 Bank Sec SD	0.51	**0.081**	0.803	0.247	0.224
20 Heading Mean	**0.008**	0.745	**0.027**	0.936	0.149
20 Heading SD	0.913	0.234	0.615	0.33	0.765
20 Heading Sec Mean	0.701	0.591	0.172	0.937	**0.087**
20 Heading Sec SD	**0.046**	0.42	**0.07**	0.663	0.28
30 Bank Mean	0.462	0.141	0.327	0.296	0.793
30 Bank SD	0.955	0.655	0.491	0.951	0.812
30 Bank Sec Mean	0.875	0.703	0.891	0.814	0.569
30 Bank Sec SD	**0.099**	0.336	0.331	0.682	0.494
30 Heading Mean	0.541	0.471	**0.035**	0.203	0.489
30 Heading SD	0.832	0.788	0.556	0.299	**0.059**
30 Heading Sec Mean	0.757	0.262	0.104	0.811	**0.017**
30 Heading Sec SD	0.149	**0.045**	0.979	0.964	0.632
40 Bank Mean	0.64	0.896	0.211	0.312	0.624
40 Bank SD	0.126	**0.082**	0.744	0.52	0.484
40 Bank Sec Mean	0.683	0.191	0.721	0.796	0.648
40 Bank Sec SD	0.105	0.748	0.26	0.482	0.289
40 Heading Mean	0.901	0.612	0.295	0.68	0.74
40 Heading SD	0.169	0.177	0.383	**0.012**	0.813
40 Heading Sec Mean	0.519	0.744	0.801	0.672	0.366
40 Heading Sec SD	0.823	0.262	0.5	0.332	0.979
50 Bank Mean	0.715	0.659	0.46	0.933	0.696
50 Bank SD	0.83	0.157	0.896	0.727	0.323
50 Bank Sec Mean	0.76	0.999	0.674	0.218	**0.048**
50 Bank Sec SD	0.24	**0.051**	0.383	0.206	0.202
50 Heading Mean	0.15	0.672	0.331	0.214	0.338
50 Heading SD	0.801	**0.08**	0.715	0.675	**0.024**
50 Heading Sec Mean	**0.084**	0.708	0.445	0.435	**0.043**
50 Heading Sec SD	**0.047**	0.159	0.429	0.553	**0.098**
Level Bank Mean	0.556	0.336	0.696	0.325	0.224
Level Bank SD	0.916	0.341	0.519	0.633	0.746
Level Heading Mean	0.714	0.482	0.832	0.11	0.987
Level Heading SD	0.832	0.57	0.455	0.561	0.502
Level Sec Mean	0.148	0.907	0.55	**0.022**	0.274
Level Sec SD	**0.004**	0.622	0.73	0.84	0.821

Significance Values for Discrete Events

	Sudden Attitude Upset	
	One Degree	Two Degree
HFIRST	0.101	0.101
ADI	0.010	0.535
ADI*HFIRST	0.001	0.000
MOTION	0.048	0.064
MOTION*HFIRST	0.493	0.898
SEC	0.492	0.867
SEC*HFIRST	0.791	0.617
ADI*MOTION	0.761	0.650
ADI*MOTION*HFIRST	0.431	0.452
ADI*SEC	0.240	0.490
ADI*SEC*HFIRST	0.366	0.390
MOTION*SEC	0.063	0.208
MOTION*SEC*HFIRST	0.739	0.887
ADI*MOTION*SEC	0.828	0.231
ADI*MOTION*SEC*HFIRST	0.106	0.467

	Unusual Attitude Recovery	
	One Degree	Two Degree
HFIRST	0.320	0.045
ADI	0.601	0.156
ADI*HFIRST	0.014	0.006
MOTION	0.183	0.068
MOTION*HFIRST	0.721	0.578
ADI*MOTION	0.160	0.595
ADI*MOTION*HFIRST	0.733	0.819

Significance Values for Discrete Events

	Sudden Attitude Upset	
	One Degree	Two Degree
HFIRST	0.101	0.101
ADI	**0.010**	0.535
ADI*HFIRST	**0.001**	**0.000**
MOTION	**0.048**	**0.064**
MOTION*HFIRST	0.493	0.898
SEC	0.492	0.867
SEC*HFIRST	0.791	0.617
ADI*MOTION	0.761	0.650
ADI*MOTION*HFIRST	0.431	0.452
ADI*SEC	0.240	0.490
ADI*SEC*HFIRST	0.366	0.890
MOTION*SEC	**0.063**	0.208
MOTION*SEC*HFIRST	0.739	0.887
ADI*MOTION*SEC	0.828	0.231
ADI*MOTION*SEC*HFIRST	0.106	0.467

	Unusual Attitude Recovery	
	One Degree	Two Degree
HFIRST	0.320	**0.045**
ADI	0.601	0.156
ADI*HFIRST	**0.014**	**0.006**
MOTION	0.183	**0.068**
MOTION*HFIRST	0.721	0.578
ADI*MOTION	0.160	0.595
ADI*MOTION*HFIRST	0.733	0.819

Mean Square Errors for Continuous Events

	HFIRST	ADI	MOTION	SECTASK
20 Bank Mean	0.4760	0.5560	0.5170	0.6010
20 Bank SD	1.3440	0.3360	0.2970	0.3790
20 Bank Sec Mean	0.0014	0.0010	0.0056	0.0017
20 Bank Sec SD	0.0023	0.0009	0.0007	0.0025
20 Heading Mean	0.6770	0.4280	0.4130	0.2230
20 Heading SD	0.1060	0.0400	0.0349	0.0220
20 Heading Sec Mean	0.0032	0.0013	0.0013	0.0029
20 Heading Sec SD	0.0023	0.0015	0.0009	0.0047
30 Bank Mean	0.7110	0.3910	0.3420	0.6840
30 Bank SD	0.9940	0.2320	0.1230	0.0749
30 Bank Sec Mean	0.0058	0.0033	0.0028	0.0033
30 Bank Sec SD	0.0048	0.0025	0.0008	0.0031
30 Heading Mean	0.4230	0.5670	0.4090	0.4150
30 Heading SD	0.1850	0.0319	0.0387	0.0598
30 Heading Sec Mean	0.0022	0.0011	0.0027	0.0032
30 Heading Sec SD	0.0043	0.0028	0.0023	0.0033
40 Bank Mean	0.6290	0.4400	0.4500	0.4510
40 Bank SD	0.9980	0.4280	0.2040	0.1220
40 Bank Sec Mean	0.0023	0.0019	0.0013	0.0025
40 Bank Sec SD	0.0054	0.0022	0.0013	0.0028
40 Heading Mean	0.6420	0.6960	0.8010	0.6610
40 Heading SD	0.1740	0.1020	0.0702	0.0386
40 Heading Sec Mean	0.0042	0.0042	0.0018	0.0028
40 Heading Sec SD	0.0093	0.0040	0.0028	0.0047
50 Bank Mean	0.4160	0.5950	0.3640	0.5820
50 Bank SD	1.1510	0.2930	0.1930	0.1300
50 Bank Sec Mean	0.0031	0.0012	0.0024	0.0045
50 Bank Sec SD	0.0083	0.0055	0.0062	0.0056
50 Heading Mean	6.0780	4.0190	5.2490	2.8340
50 Heading SD	0.3250	0.1100	0.0483	0.0495
50 Heading Sec Mean	0.0047	0.0022	0.0015	0.0044
50 Heading Sec SD	0.0066	0.0020	0.0029	0.0040
Level Bank Mean	0.3450	0.4770	0.4340	0.1840
Level Bank SD	10.2850	2.9530	1.1200	0.9530
Level Heading Mean	1.7880	2.5000	2.0940	1.0550
Level Heading SD	1.5790	0.5070	0.2830	0.1560
Level Sec Mean	0.0008	0.0010	0.0006	0.0014
Level Sec SD	0.0067	0.0036	0.0027	0.0065

Mean Square Errors for Discrete Events

	HFIRST	ADI	MOTION	SECTASK
One Degree Sudden Upsets	1.690E-01	5.525E-02	1.130E-01	1.130E-01
Two Degrees Sudden Upsets	1.240E-01	2.947E-02	7.682E-02	4.557E-02
One Degree Unblanks	8.845E-03	1.169E-02	7.764E-03	
Two Degrees Unblanks	3.977E-03	4.243E-03	3.192E-03	

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14. ABSTRACT

(U) This report presents the results of an experimental program designed to study the relative merits of a conventional moving horizon attitude director indicator (ADI), and an alternate ADI called a frequency separated display. The program is based on the investigation of the performance of naïve test subjects (with no previous ADI experience) while flying a number of lateral control tasks under instrument meteorological conditions in a flight simulator set up as a T-33 jet trainer.

Four lateral flying tasks were developed and employed: level tracking, heading changes, sudden attitude upsets, and unusual attitude recoveries. In addition, two secondary tasks (one audio and one visual) were employed in order to increase the overall workload and to provide a measure of level of attention required by the primary flying task.

A total of 24 subjects participated in the study, with approximately 14.5 hours of simulator time each. Both objective and subjective measurements were taken, with the independent experimental variables being: ADI type, simulator motion present/absent, and secondary task type.

The experimental results indicate that ADI type was not significant in the heading changes task. However, subjects displayed improvement in performance using the frequency-separated display for the level tracking tasks.

The primary measurement of pilot performance in the sudden attitude upsets and unusual attitude recoveries was the number of control reversals (where the pilot aileron input is in the opposite direction to that which is required to return the aircraft to wings level). Fewer control reversals (as defined using two different criteria) were committed using the frequency-separated display for sudden attitude upsets. The same improvement in performance was also noted when using the frequency-separated display for unusual attitude recoveries for the more stringent of the two criteria. For both sudden attitude upsets and unusual attitude recoveries, the pilot aileron input also appeared to be more consistent with less overshoot when using the frequency-separated display.

Overall, performance with the frequency-separated display was generally either similar to or superior to that with the conventional ADI.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) attitude display; frequency separated display; aviation; human factors; control reversal

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